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DEVELOPMENT OF UREA-BASED AND LATEX EMULSION SYSTEMS FOR DUST CONTROL IN SUPPORT OF MILITARY OPERATIONS

by

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FOREWORD

This publication reports the results of work performed under Contract No. DA-22-079-eng-484 between the U.S. Army Engineer Waterways Experiment Station and Dynatech Corporation sponsored by the U. S. Army Materiel Command under Department of the Army Project 1-V-0-21701-A-046, "Trafficability and Mobility Research", Task 05, "Mobility Engineering Support (Dust Control, Southeast Asia)."

The objective of the program was the development of methods and materials to control dust in connection with military operations on roads and airfields in the theater of operations. The work carried out was directed toward formulation of an aqueous polymer dispersion suitable for simple application on soils by spraying.

Staff members of the Chemical Engineering and Fluid Mechanics Group at Dynatech Corporation who were active in this program were: Nicholas J. Caswell, John E. Ehrreich, Gerald B. Gilbert, Adrian R. Reti, Jacques P. Tramoni, and Ralph L. Wentworth. The work was carried out during the Period April 28 - October 28, 1966.

The contract was monitored by Mr. G. R. Kozan, Chief, Stabilization Section, Expedient Surfaces Branch, under the general supervision of Mr. W. J. Turnbull, Chief, Soils Division, Waterways Experiment Station. Contracting Officer was COL J. R. Oswalt, Jr., CE.

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SUMMARY

This report presents the results of a program directed towards the development of materials for use by the military for dust control in the theater of operations. Criteria for defining the desirable properties of such dust control agents have been established, and materials which possess these properties have been procured, formulated, tested, and evaluated.

The low material usage rates required (3 lbs per square yard or less) plus the variety of soils and soil conditions over which such dust control agents must be used preclude such treatments from adding to the load bearing capacity of the soil to any appreciable extent. The materials developed, therefore, are designed to be sprayed as liquids on the soil surface and to produce coherent, highly flexible and extensible surface layers which effectively seal off the soil surface, preventing generation of dust. The flexible layers formed can withstand considerable deformation without failure. Because of their nature, these dust control agents serve to waterproof the soil as well.

Several latex formulations have been developed which passed the laboratory screening tests and which show potential for military dust control purposes. A device has been developed for the simple application of these materials.

Urea resin formulations were examined initially and determined to be generally ineffective, due primarily to their inability to withstand deformations of great enough magnitude. Subsequently, emphasis was directed toward synthetic and natural latex systems which show a greater potential.

1. INTRODUCTION

1.1 Problem Statement

1. An increasing need has developed for dust control agents which satisfy a wide range of requirements from the viewpoint of the coating properties, versatility and ease of application. While such requirements are described in detail in the Department of the Army's Qualitative Materiel Requirement (QMR) for Dust Control Materiel, a brief summary is presented here of the requirements which govern the selection criteria for the desirable properties that dust control materials and their related application equipment should possess.

1.1.1 Problems Created by Lack of Proper Dust Control in the Theater of Operations

2. Dust control agents are required for use around airfields, helicopter landing areas, operational bases, intermediate and cantonment areas and auxiliary roads. At present, improved dust control constitutes an urgent requirement in the theater of operations. The presence of dust creates several problems.

a. Drastic reduction in "usage expectancy" of machinery and equipment, such as helicopter rotor blades and engines.

b. Dust impairs visibility, creating a safety hazard and limits the intensity with which a particular area can be used (i.e., frequency of aircraft landings).

c.. Dust clouds make the areas of operations visible from afar.

d. Dust impairs the health and morale of the personnel in the area.

1.1.2 Required Characteristics of Dust Control Material

3. The criteria for evaluation of dust control agents can be broken down into three general areas. Each of these areas contains certain requirements which must be met in order that a dust control system be suitable for military use. These three general areas comprise application, performance and durability of the dust control systems.

a. Application. Dust Control materials must:*

(1) "Be effective and operationally usable within four hours after application to the surface of all types of soil.

---

*Statements under quotation marks from QMR of August, 1966 (Reference 1)

(2) "Weight and volume characteristics of the material shall not exceed three pounds (or 0.45 gallons) per square yard of ground surface treated on trafficked areas. If material requires dilution with water for application, volume shall not exceed two gallons per square yard.

(3) "Be noncorrosive and noninjurious to metals, alloys, rubber and plastics, be compatible for use in conjunction with prefabricated landing mats and membrane surfacings and suitable for trafficking by aircraft, ground vehicles and application equipment without adverse effect to these.

(4) "Be nontoxic, noninjurious and noncontaminating to human beings, animals, water supplies and agricultural areas after being applied.

(5) "Be nonflammable, and nonexplosive within specified conditions of handling, storage and application, and fire retardant after being applied to soil surfaces.

(6) "Be capable of being used, stored and transported under the following conditions AR 705-15 (Ref. 2):

(a) Use: Intermediate, hot - dry and warm - wet climatic conditions, excluding precipitation, wind greater than 20 knots and ambient air temperature below 40 degrees Farenheit.

(b) Storage: Intermediate and high temperature storage conditions. (Open storage under humid, tropical conditions for three years)

(c) Transit: Air transit conditions."

(7) The equipment used to apply this material must be compatible with it and be able to operate at the application rates specified by the QMR.

b. Performance. The Dust Control materials applied must:

"Withstand, without failure or peeling, helicopter rotor downwash (10 psf disc loading) and C-130 aircraft propwash (100 mph air velocity)." A dust control material is effective if it prevents the soil particles and other debris from being entrained in the airstream. Even if the material is one hundred percent effective in this respect, it is clear that its overall effectiveness in a given area will be a function of the coverage achieved, there being areas which will either have been missed during

application or where the coatings will have failed due to outside causes such as excessive traffic loads.

c. Durability. Dust Control materials must:

"Be effective, with only minor maintenance, for the following minimum time:

(1) Six months in nontraffic areas

(2) Three months in areas subjected to infrequent traffic of ground vehicles or aircraft, such as shoulders and overruns.

(3) One month in areas trafficked by ground vehicles or aircraft."

These requirements represent a definite demand on the aging characteristics of the material to be used in terms of the retention of its physical properties under the effects of moisture cycling, ozone exposure, and ultraviolet (sunlight) irradiation.

1.2 Problem Approach

1.2.1 Desirable Properties of a Dust Cover

4. The required characteristics of the dust control material, as described in Section 1.1.2, allow the determination of the necessary and desirable properties that a dust cover should possess.

a. Thickness. The limitation that a maximum amount of material to be used should not exceed 3 lbs. per square yard sets the maximum thickness of a coating composition having a specific gravity of one to 0.060", or 0.030" if the material is used with 50% by weight of a carrier liquid. While it is conceivable that such additives could be used in small amounts to "cement" soil particles to each other, overall treated soil thicknesses greater than 0.5" cannot be expected even with excellent penetration of a dilute dust control agent.

b. Strength. No such coating, neither the homogeneous, continuous film nor the thicker "crusts" formed can be expected to contribute substantially to the load-bearing properties of the soil. The strengths of such surface layers are, however, quite satisfactory to prevent dust and debris from being entrained into the air stream of operating aircraft. It is clear, therefore, that the problem of adequate strength concerns preventing failure of these dust covers under traffic. Since the amounts of

material are insufficient to provide adequate load-bearing strength to the soil, and in many cases such as with sand or uncompacted silts or clays the soils experience severe deformations and rutting under traffic, an approach that offers promise is one whereby the dust cover layer can deform to a large extent without failure. Strength in such a flexible film is useful mostly because a stronger film can transfer the local loads to more distant points in the film, and thus get the membrane to elongate all the way from such distant points. Strengths of over two pounds per linear inch of membrane have appeared to be adequate to withstand traffic.*

c. Elongation. The above discussion indicates that high elongation of the coating is a desirable property. Considering the types of rutting produced by vehicular traffic on sandy soils, elongations of the order of several hundred percent may be necessary. Complete recovery of the film is not necessary. Permanent set, leaving the film to conform to the new terrain surface may prove to be more desirable, since stretched membranes with air gaps below them may favor "ballooning" and stripping of the soil cover under wind blast conditions.

d. Penetration of the Material. If high elongation is a desirable property of the dust cover, the material must penetrate the soil only to a limited extent (to provide a bond with the soil surface). Penetration results in the incorporation of the soil particles into the coating as a filler, and such addition may reduce drastically the elongation properties of a film.

e. Aging. The dust cover, being on the soil surface, and therefore exposed to the elements (rain, oxygen, ozone, sunlight) must have adequate weathering characteristics.

f. Permeability. The dust cover should be impermeable, since in this fashion the load-bearing strength of dry soil will be maintained during precipitation periods (in the case of silts and clays) and the washout of the soil substrate by water runoff will be prevented.

1.2.2 General Considerations Guiding Materials Selection

5. In a review of the kinds of materials available for treating surfaces to eliminate dust (Ref. 3) the following classifications of materials were discussed:

*In order to compute the tensile strength of the membrane, the thickness can be estimated from the coverage used in lbs solids/square yard and assuming a specific gravity of 65 lb/ft^3.

a. Bituminous materials (e.g., asphalts, tars)

b. Cementing materials (e.g., cement, lime)

c. Resin systems (e.g., lignin, petroleum resins)

d. Salts (e.g., calcium chloride

e. Miscellaneous materials (e.g., water, waste oil)

The limitations of these treatments with respect to the characteristics and properties discussed above generated the interest in developing improved materials. Moderate molecular weight materials such as asphalts bind the soil particles to each other by capillary and viscous forces, and result in coatings with poor strength and elongation characteristics. There are no low-cost inorganic materials which possess the physical properties described in Section 2.2.1 (most inorganic systems performing as rigid binders which cement the soil particles together). The limited number of resin systems listed are not entirely acceptable. The salts and miscellaneous materials give only temporary palliation. The search for flexible, high elongation dust covers leads naturally to high polymer systems, and cost considerations narrow down the field to organic high polymers. Prior to the work undertaken here, relatively little investigation of the soil stabilizing properties of high polymer systems has been reported. Those which have been studied (Ref. 4) are, for the most part, rigid thermosetting resins.

6. One problem with polymer systems is that in bulk or in solution they possess high viscosities (of the order of thousands of centipoises for 20-30% solutions), making the application in this form completely impractical. For this reason, an approach based on the use of polymers as dust palliative systems must provide for their application as a low viscosity system. Such application is possible by following two approaches:

a. The use of polymer emulsions, which have relatively low viscosities (10 to 300 centipoises for 40% to 60% solids contents). Such emulsions can be coagulated on the soil surface, forming a polymer film.

b. The use of liquid monomers or monomer solutions, having low viscosities which are polymerized "in situ" after they have been applied (and sometimes penetrated) the soil.

7. Selection of the specific polymer to be used and its form for application may be made from a large variety of systems. Because of the complexity of the terminology of polymers a discussion of polymer classifications is presented in the Appendix of this report.

1.2.3 Elastomer Emulsion Systems

8. If physical properties such as high elongation are desired, polymer systems of high molecular weights such as most of the elastomers and some

vinyl polymers must be used. Typically, the true high polymers which possess adequate strength and elongation characteristics possess molecular weights of at least 10,000 and more like 100,000 in the case of rubbers. Solutions of such high molecular weight polymers have prohibitively high viscosities, and it is clear that either "in situ" polymerization or application of the polymer emulsions must be considered. Of these two the polymerization of either vinyl or elastomer monomers is a very sensitive reaction which could not be in any way carried out on the soil under field conditions. A polymer emulsion, however, is a two phase system, consisting of a continuous aqueous phase in which polymer droplets, 0.1μ to 10μ in size, are dispersed by means of a surface active agent. The discontinuous phase (the polymer) can make up as much as 60% of the total weight of the emulsion. Within any single emulsion there is a wide range in particle sizes. On aging, the small particles combine into larger ones, and as particle size increases, the emulsion viscosity increases. Such a process is dependent on the stability of a particular emulsion. Lower discontinuous phase concentrations and the presence of adequate surface active agents increase the emulsion stability. Electric charges on the particles also play a role in their stability. An emulsion may contain globules of pure polymer as well as particles of additives such as antioxidants, tack reducers, plasticizers, etc., as desired.

9. These polymer emulsions can be "broken" (the discontinuous phase coagulates into a continuous phase) by increasing the solids concentration beyond a critical level or by the addition of a substance that overcomes the effect of the surface active stabilizing agent and charge on the dispersed particles. Polyvalent ions in solution overcome the electrical double layer of an ionic surface active agent, for example, and cause the emulsion to coagulate. From these considerations, therefore, it is clear that a continuous polymer layer can be formed by either an emulsion layer or by adding to it a suitable coagulant.

10. The mechanism of film formation by the evaporation of water from a polymer emulsion or latex (latex being the generic term derived from the first known: natural rubber emulsion obtained from the hevea tree) is illustrated in Figure 1, as described by Carl (Ref. 5). In the freshly deposited liquid, the latex particles are suspended in serum and are free to move about by Brownian motion (Step 1). As evaporation proceeds, concentration increases and the particles bump into each other more and more frequently. Eventually all particles approach each other closely enough for molecular attractive forces to become effective and overcome the repulsion forces created by the charged, adsorbed surface active agent molecules. The system becomes immobilized (Step 2); at this point the film is formed but discrete particles can be observed. As evaporation proceeds further, the particles deform to fill the space vacated by the water (Step 3). Finally, the interfacial film ruptures and fusion of the particles occurs, forming an apparently homogeneous dry film.

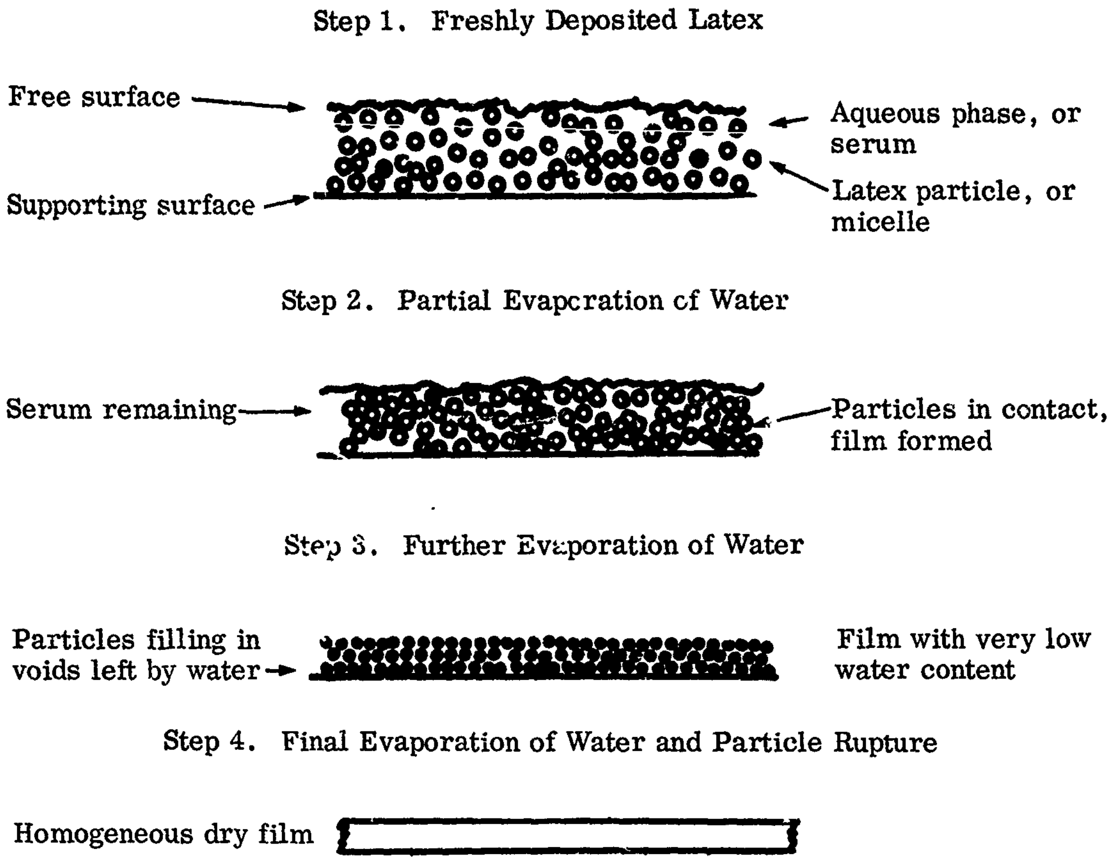

Figure 1. Representation of the Formation of a Film from Latex by Evaporation (Ref. 5)

11. When coagulants are used, the process is modified. The coagulants rapidly form an immobile network of particles which encloses most of the water originally present in the latex. At that moment the interfacial film between particles and the continuous fluid medium is destroyed by the neutralization of the space charge (electrical double layer) set up by the emulsifier, resulting in particle fusion at the early stage of film dehydration. This may account for the relatively high strength of the latex gel which probably contains all of the original water, as opposed to the lower strength of incompletely dried films obtained by evaporation and having lower water contents. Water leaves the gel structure through capillaries set up during gelation as the gel structure collapses (syneresis).

12. When a latex is sprayed on a soil, it will gradually penetrate the soil and sink into it, eventually drying and binding the soil particles together but the layer so formed has a high "filler" content, resulting in a layer of properties inferior to that of the pure polymer film. The rate of penetration into the soil is described by the phenomenon of flow through microporous solids. Gravity and surface tension times the cosine of the contact angle (usually one) provide the driving force and the pressure drop under flow provides the resistance to penetration. Since the surface tension does not vary greatly from fluid to fluid, the

penetration rate is mainly governed by viscosity and soil particle size. The penetration rate is inversely proportional to the first power of viscosity and to the first power of soil particle size when surface tension is the predominant driving force. (In this case the driving force is directly proportional to soil particle size and the resistance to flow is directly proportional to the square of soil particle diameter.) For these reasons, penetration takes place most readily in coarse grained soils such as sand.

13. Several measures can be taken to minimize such penetration of the soil. The first and most obvious one is to increase the viscosity of the emulsion. Unfortunately, there is a limit to which the viscosity can be raised and still be sprayed with simple equipment (about 100 centipoises) and at this level penetration into sandy soils is still severe. Another method, which has been developed at Dynatech, consists of pretreating the soil with a thin layer of a coagulant. When the polymer emulsion is applied, the bottom layer of emulsion in contact with the treated soil coagulates as it begins to penetrate the soil and is acted upon by the coagulant. This coagulated film "plugs" the pores and prevents further penetration. Diffusion of some of the coagulant salts into the rest of the emulsion furthers coagulation of the film in some cases. A coagulant could, as well, be sprayed afterwards on top of the emulsion, to set it faster than by drying action alone. Such second spray of coagulant can be achieved by having the coagulant nozzles trailing or pointing behind the latex nozzles.

14. A film left on the surface by means of a coagulant has superior mechanical properties to an air dried film (higher elongation) and achieves its strength faster by drying faster on the soil surface and by being at least partially coagulated even before drying.

15. The types of polymer systems most promising for this application were selected on the basis of their mechanical and aging properties. The polymer systems tested included natural rubber (unvulcanized and prevulcanized) synthetic rubbers such as SBR, Neoprene and Nitrile Rubbers, polyacrylates, polyvinyl acetate and plasticized polyvinyl chloride. Because of the short duration of the program, most of these materials were tested in the form of proprietary formulations, which were prepared for some particular use other than the present one, and therefore in many cases contained additives which were even detrimental to their performance. Small changes in formulation such as the type of surface active agent introduced with additives resulted in drastic changes in dust control agent performance. In one case, a nonionic surface active agent was used by the formulator of a latex to aid in the addition of an antioxidant to the system. The presence of this surface active agent turned a system of excellent coagulation properties into a marginal one. Eventually, a complete control over the system formulations will be necessary to ensure maximum performance for the specific use of such polymer emulsions as dust control agents.

1.2.4 Thermosetting Resin Systems

16. Before the need for coatings with high flexibility and elongation was established, the approach whereby the solution of a "B stage" thermosetting resin was allowed to penetrate a soil and crosslink (cure) in place in a matter of seconds to minutes appeared very attractive. At the outset of the investigation, urea-based

systems were examined, and while good coatings generally resulted, it was evident that their capabilities were limited in that the films formed were unable to tolerate deformations to the extent required to support traffic. Consequently, with the concurrence of WES, emphasis was shifted toward examination of the elastomer emulsion systems.

17. In general, urea-formaldehyde, furfuryl alcohol modified urea systems or melamine modified urea systems were considered for this use, in the form of water solutions with 20 to 65% solids content. Catalysts are needed to set these systems at room temperature (the idea is to mix the catalyst with the resin solution in the spray nozzle just before application), and the most successful are acid-setting systems. The addition of plasticizers to increase the flexibility of the resulting films was considered, but not investigated experimentally.

1.2.5 Further Considerations of Fluidity

18. The need to adjust the viscosity of a dispersion or solution in order to adjust penetration and permit ready spraying has been discussed above. A further phenomenon affecting the viscosity is that of crack generation on wetting of soils. When unconsolidated soils are lightly wetted the forces of capillary attraction generated between the wetted particles cause localized segments of the wetted soil area to draw together. As such segments draw together in random fashion, cracks and fissures are created between the segments. Further fluid applied to the surface then collects in these cracks.

19. The fissuring of soil just described cannot be avoided, and in the procedures of two-stage spraying tested in this work the fissuring is caused by the initial application of coagulant solution. The latex or polymer solution is then necessarily applied to a fissured surface when unconsolidated soils are treated. Indeed, some soils may be encountered in the field with cracks already present because of previous natural wetting. It is necessary for the latex to flow into, coagulate in, and coat these fissures. The need for such flow to occur sets an upper limit on the viscosity of the applied latex or polymer solution. If the viscosity is too great the flow toward and into the fissures will be so slow that the fluid is coagulated before adequately treating the fissures. This need establishes another restriction on viscosity independent of the need to regulate viscosity from the standpoints of pumping pressures and soil penetration.

2. EXPERIMENTAL PROGRAM

2.1 Testing Criteria

20. Many assumptions have to be made when attempting to evaluate a dust control material that has to be applied over acres of varied terrain and a wide range of soil types and conditions. Since full scale field tests are out of the question at the screening and even beyond the screening stages for more than a very limited number of materials, some evaluation criteria that permit a laboratory scale evaluation must be established. The laboratory test procedures developed at WES (Ref. 6) provide some of these evaluation criteria, as do the limited traffic test evaluations (Ref. 7) and the downwash blast tests (Ref. 8). Some of these tests were adopted for internal evaluation at Dynatech. Other tests, such as tensile strength and elongation of the formed membranes, ozone, ultraviolet and high temperature aging of samples were developed to provide additional relative performance data on the dust control materials evaluated.

2.1.1 Soil Sample Selection

21. For the laboratory screening tests, three different soils were selected which are considered to be dust problem types and which would reflect the effectiveness of a dust control material over a range of soils that would be encountered in the field. The soils selected, with the concurrence of the WES, were a uniformly-sized sand, a clayey silt and Potters Flint. As it turned out, the soil type in which it is most difficult to pass not only the laboratory screening tests but also traffic tests is the sand (high porosity, large pore sizes); thus, most of the evaluation tests and experiments on improved formulations were performed on the sand. Only after the behavior in sand was established were the coating materials evaluated in the other soils.

22. Figure 2 shows the particle size distribution curves for the sand used in dust control research at WES and the York Beach, Me., sand used in the tests at Dynatech. The York Beach sand is coarser than the WES sand. In the later phases of the program a sand designated as #55 was used. The gradation of #55 matches that of WES sand.

23. Figure 3 shows the particle size distribution gradation curves (wet and dry sieving) and Atterberg Limits of a Massachusetts Clayey Silt used. This soil is classified as CL-ML according to the Unified Classification System and is slightly more plastic than a clayey silt (ML) used in tests by the Waterways Experiment Station. The dry sieve analysis of the soil after grinding and passing through a No. 40 sieve shows that the dry soil contains approximately 40% fines (-#200 sieve). The wet sieving and hydrometer analysis show that the soil actually contains 70% fines and 15% clay size particles (-2μ).

24. Figure 4 shows the gradation curve for the Potters Flint, which has essentially the same grain size distribution in the wet as in the dry states.

25. No fat clays have been tested in the present program.

26. The soils were tested under the following conditions:

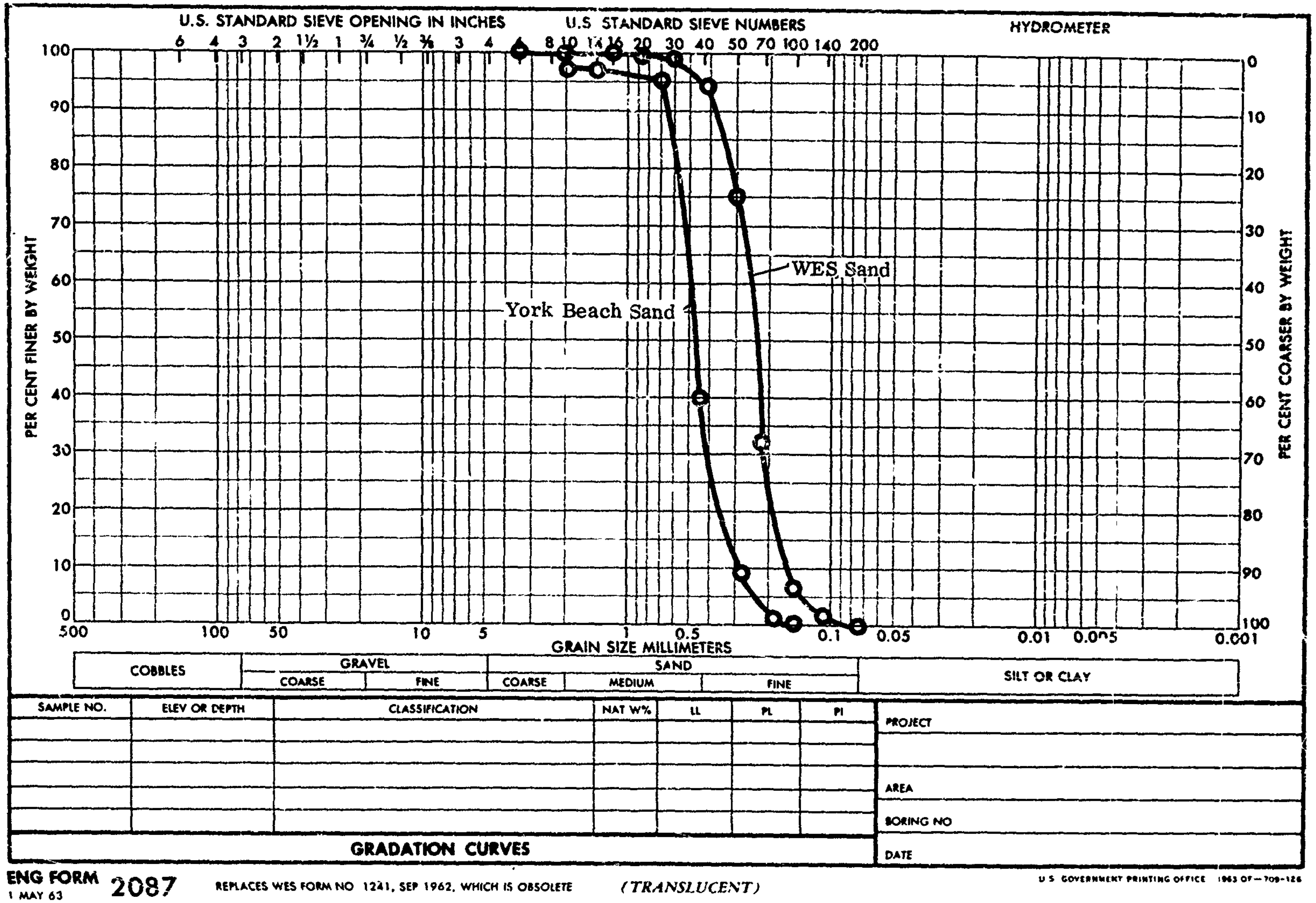

Figure 2. Gradation of York Beach Sand and WES Sand (SP), Tan

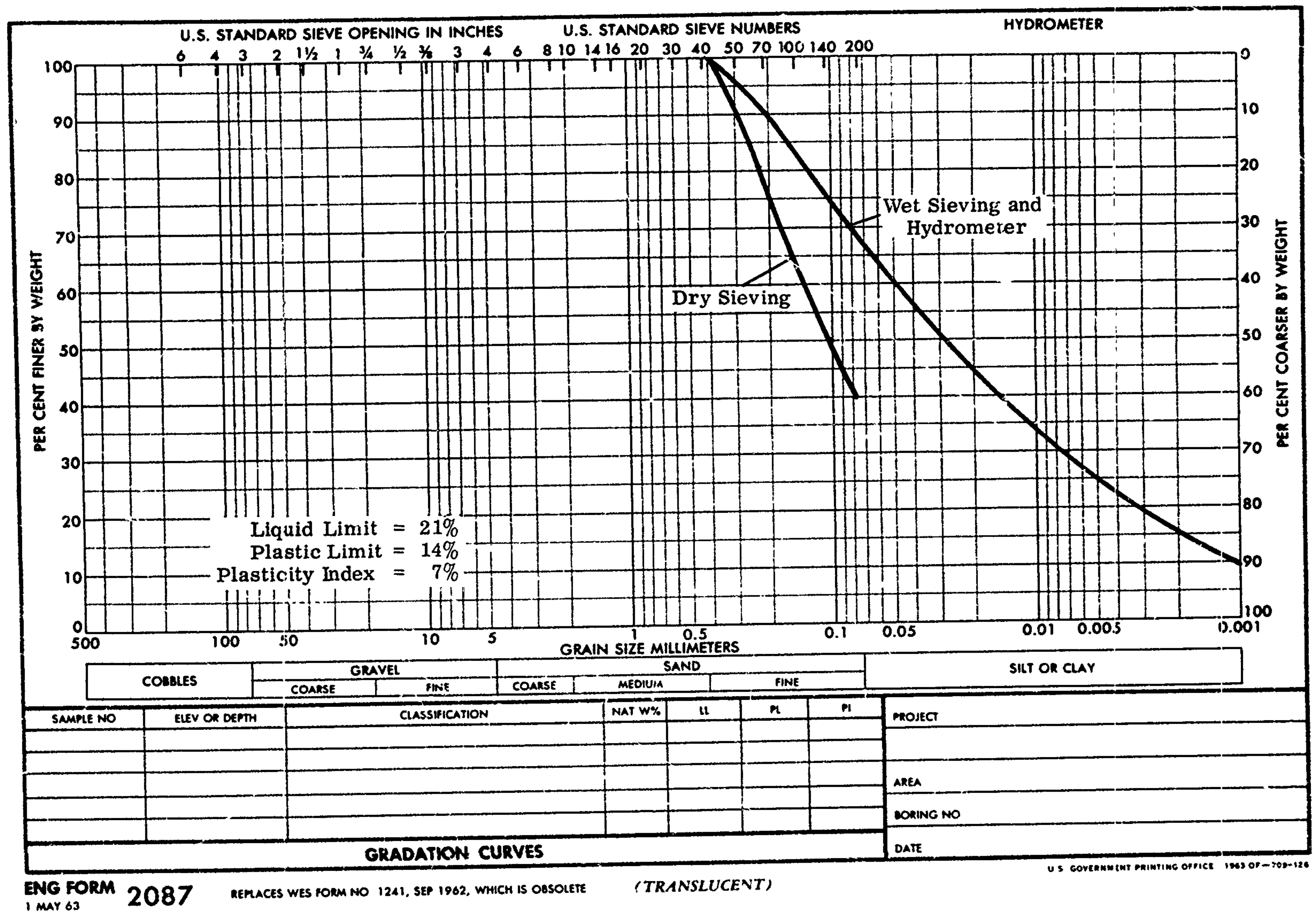

Figure 3. Gradation of Massachusetts Clayey Silt

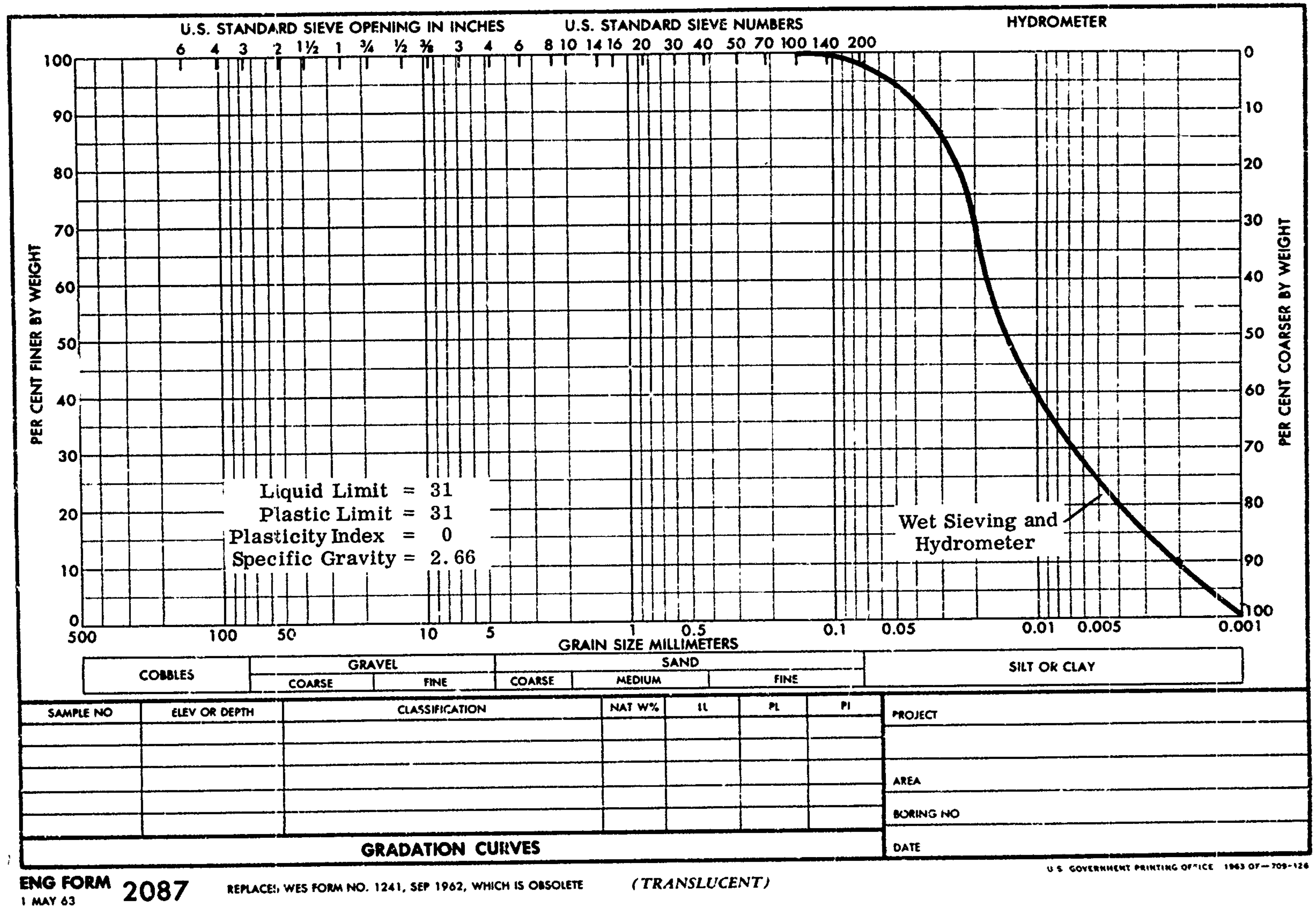

Figure 4. Gradation of Potter's Flint

a. York Beach Sand, loose, uncompacted, < 1% moisture.

b. Massachusetts Clayey Silt (-40 mesh).

(1) Loose, uncompacted, 2.1% moisture.

(2) Compacted to 90 lb/ft^{3*}, 12 to 16% moisture.

c. Potters Flint (silica, -324 mesh).

(1) Loose, uncompacted, < 3% moisture.

(2) Compacted to 90 lb/ft^3, 12 to 18% moisture.

2.1.2 Test Procedures

27. Several test procedures were adopted in order to establish consistent comparison criteria for the materials evaluated.

a. Laboratory preliminary screening tests. The soil samples were placed in steel pans 6.3" x 6.3" x 3" high, and underwent a set of tests quite similar to the ones described in Reference 6 (WES Laboratory Screening Tests). These included:

(1) Air impingement test. The test surface was subjected to air blasts of 7, 30, and 55 psf stagnation pressures from a circular nozzle, each for one minute duration, and impinging at an angle of 20°. The air blast pressure is monitored by means of a pitot tube manometer assembly.

(2) Rainfall erosion test. Consists of a shower nozzle with a 6-inch constant head reservoir. The specimens are held for one hour under water erosion conditions.

(3) Drying under ambient laboratory conditions for 20 - 24 hours.**

(4) Infrared heating at equilibrium surface temperature of 120°F.

The sequence of tests used was as carried out at WES, namely, (1), (2), (1), (3), (4), (1).

* For the higher moisture samples the material was compacted to densities higher than 90 lb/ft^3 as large voids existed between lumps.

**The 24-hour drying time allowed for more complete drying and exposed the most pronounced dimensional changes that could take place in the coatings and substrate.

b. Tensile and elongation. The polymer films formed on soil samples were cut into dumbell-shaped tensile test specimens, and their tensile strength and maximum elongation on break were recorded. These data provide evaluation of the relative resistance to rutting of the different materials under a variety of application conditions.

c. Accelerated aging. Three different aging studies were carried out on films which were dried at ambient conditions. The films were prepared by drawbar coating 15 mil thick layers and drying the latices on mylar film.

(1) Heat aging. This test involved placing strips of the dried film in an 100°C oven for 90 hours, and then measuring the mechanical properties of the samples.

(2) Ozone resistance. Similar but smaller strips of the different films were exposed to an ozone environment for 7 days. Two samples of each material were used, one in the unstretched state and one stretched by 15 percent.

(3) Ultraviolet (U. V.) resistance. Samples of the film were exposed in the Fade-O-Meter for a period of 72 hours. This instrument subjects the samples to intense ultraviolet radiation. Discoloration, stiffening and cracking of the samples are usually observed, and the extent to which these take place provide a relative evaluation for the U. V. resistance of a given film.

d. Occasional traffic. A very simple test was performed. A film of dust control agent on a sand plot 3 ft x 3 ft x 1 ft deep was laid down by conventional spraying techniques, and after a suitable drying period (i.e., 4 hours) subjects walked and a vehicle was driven over the plot. The purpose of this test was to provide a qualitative evaluation of the rut formation and the film behavior under such traffic conditions (the sand soil providing the worst possible conditions to be encountered). This did not form part of any regular evaluation procedure for all the materials tested.

2.2 Experimental Results

2.2.1 Laboratory Screening Tests

28. A summary of 119 laboratory screening tests performed on a variety of materials is presented in tabular form in the Appendix.

29. In the early tests, a urea resin, acid-cured system was studied in detail. Coatings prepared from this system passed the laboratory screening tests in several instances. In other instances surface cracks formed or the coating lifted, leading to eventual failure. In all cases, the urea resin coatings formed were rigid and would fail under severe deformation of the underlying soil

(as a vehicle wheel load would impose). A partly plasticized urea resin system (a mixture of an acid cured urea resin with an emulsion of polyvinyl acetate) was evaluated in experiment 8, and produced a more flexible coating. Figure 5 shows the test specimen after it underwent the wind-rain test sequence plus a load test with a 3 inch x 3 inch ram. The advantage of this system is that it sets up (due to the urea system cure) in a matter of minutes, and the added polyvinyl acetate increased the flexibility of the film. Such a compound, however, penetrates a sand soil and has very limited flexibility under those conditions, and it is clear that the dust cover obtained in sand with the urea/polyvinyl acetate system will fail under load.

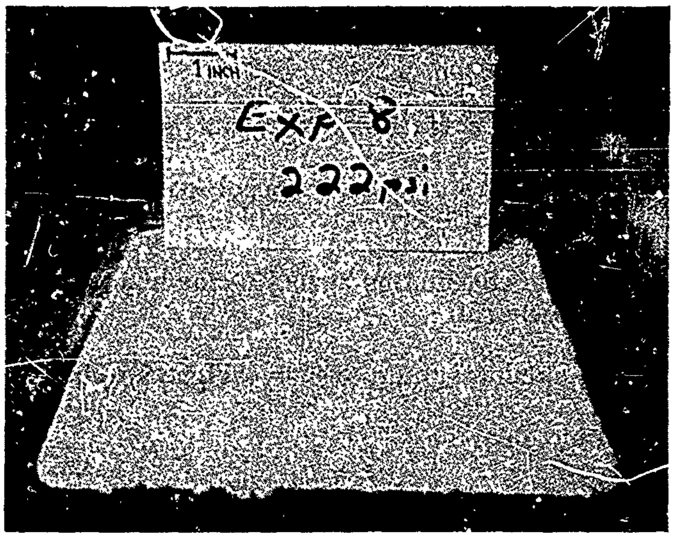

Figure 5. Urea Resin/Polyvinyl Acetate Coating Specimen after Test No. 8

30. The realization that no plasticizer would give urea resin-based coatings the elongation needed to withstand traffic led to a shift in emphasis towards elastomer systems. Since the advantages of a quick setting system can be also obtained in pure elastomers (which are capable of much greater elongations) by the proper use of coagulants, most of the formulations tested were flexible polymer emulsions and a variety of coagulating agents. Some of the variables studied are listed below:

a. Polymer composition

(1) Polyacrylates

(2) Neoprene

(3) Prevulcanized rubber

(4) Natural rubber

(5) Polyvinyl acetate

(6) Styrene-butadiene rubber (SBR)

Table III in the Appendix contains the source and composition of the resin systems tested. The results of laboratory evaluation of these materials are presented in Table I of the Appendix.

b. Additives

(1) Antioxidants

(2) Tack reducers (e.g., Polymul C-66 polyethylene emulsion)

(3) Types of surface active agents

(4) Thickeners such as Carbopol (polyacrylic acid) or sodium carboxymethyl cellulose

c. Curing and coagulating agents (acids and polyvalent cation salts in general)

(1) Aluminum sulfate (30% by weight aqueous solution)

(2) Zinc chloride (30%)

(3) Phosphoric acid (6.6, 8, 13.8, 22.5%)

(4) Calcium chloride (30%)

(5) Calcium nitrate (30%)

(6) Zinc nitrate (30%)

Two coagulating agents which proved to be superior to phosphoric acid (less toxic, easier to handle, more effective) were zinc chloride and aluminum sulfate. The aluminum sulfate coagulated the high solids latices with little contraction in the resultant coating. While the number of experiments was limited, the zinc chloride appeared to produce stronger rubber coatings from prevulcanized natural rubber latices than obtained with other coagulating agents. Possibly a crosslinking effect accounts for this. The coagulating agents produced rubbery surface coatings which were much superior in elongation and tensile strength over the non-coagulated coatings produced by drying alone. Emphasis was placed on anionic and cationic emulsified latices since these systems coagulate in the presence of polyvalent ions or acids. The sequence for adding the coagulating agent and the latex was first studied with 8% phosphoric acid and Neoprene 750. On loose clayey silt it made little difference whether the acid is sprayed first, last or alternated in a series of light coats as long as the latex coating is applied while the surface is hydrophilic (experiments 28, 29, and 30).

31. Separate application of latex and coagulant was generally practiced, but some investigation was made of the possibility of coagulating the latex while in flight from the spray nozzle to the ground. This was tested by arranging two spray nozzles side by side. Such coagulation of the Neoprene 750 in air or dual spraying with an acid spray resulted in a porous rubbery coating that failed in the initial wind blast (experiments 24, 25, and 26). On loose fine particle soils it appeared very easy to coagulate a latex and pass the environmental tests.

32. When coagulation studies were carried out on loose, coarse soils, such as beach sand, it became apparent that latex viscosity was a factor in obtaining coagulation on the surface rather than within the soil. When sprayed on beach sand which had a previous coating of 8% phosphoric acid both Neoprene 400 and 750 did not coagulate on the surface of the sand but penetrated (experiments 78 and 79). Because of the penetration of the sand by the coating this preparation was a failure in the environmental tests. However, by increasing the viscosity of Neoprene 750 from 15 cp to 270 cp (experiment 83) by the addition of sodium carboxymethyl cellulose it was possible to slow down the penetration rate so that the coating coagulated on the surface.

33. On loose clayey silt soils many polymer latices coagulated by 8% phosphoric acid gave coatings that passed the environmental tests (experiments 29, 31, 32, 34, and 38). Qualitatively the coating with least tack, highest strength and best elongation was a prevulcanized natural rubber (Vultex 1-V-10).

34. Vultex 1-V-10 coatings were applied to several soil samples (beach sand, clayey silt and Potters Flint) prepared by varying soil densities and moisture content. The conditions that gave an excellent rubber coating on any soil surface were the spraying of 0.7 pounds per square yard of 8% phosphoric acid, followed by application of 2.3 pounds per square yard of undiluted Vultex 1-V-10 (60% solids). Lowering the viscosity of Vultex 1-V-10 from 142 cp at 60% solids to 14 cp at 40% solids gave coatings on sand which had a little more penetration. A slightly different formulation, however, 1-V-10F, which contains a nonionic dispersing agent used with the antioxidant failed to form a surface coat on sand when diluted to 40% solids. A viscosity vs. temperature plot of 1-V-10 is shown in Figure 6, and a viscosity vs. concentration plot is shown in Figure 7.

35. A gallon sample of Vultex 1-V-10 with the method of application using 10% phosphoric acid was sent to Vicksburg for verification of our laboratory results. After laboratory screening tests by WES confirmed the potential of this material, larger amounts were ordered for small-scale field testing by WES.

36. Many multivalent cation salts and acids coagulate anionic latices. Eight to ten percent phosphoric acid gives fast coagulation, and produces a coating with good strength and elongation properties. Salts such as calcium nitrate and zinc nitrate gave coagulated coatings that withstood initial wind and rain tests, but under the heat lamp the oxidizing property of the nitrate anion broke down the rubber coating (experiments 56, 57, 58, and 62). Other salts and acids such as nickel chloride, tartaric acid, calcium chloride and hydrochloric acid gave weak coagulated coatings that failed the initial wind test. Sulfuric acid had a degrading affect on the rubber coating while under the heat lamp.

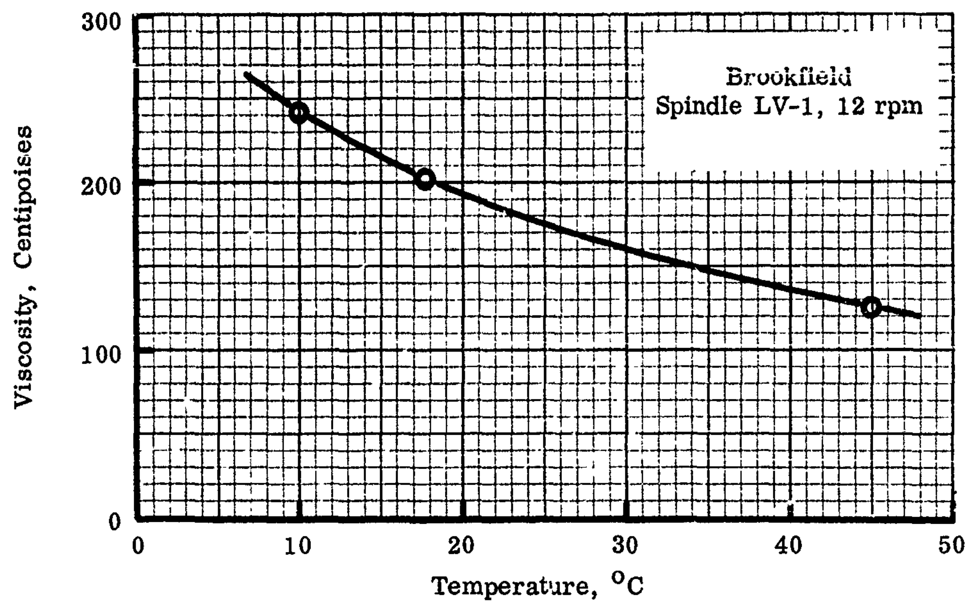

Figure 6. Effect of Temperature on Viscosity of Vultex 1-V-10G (60% Solids)

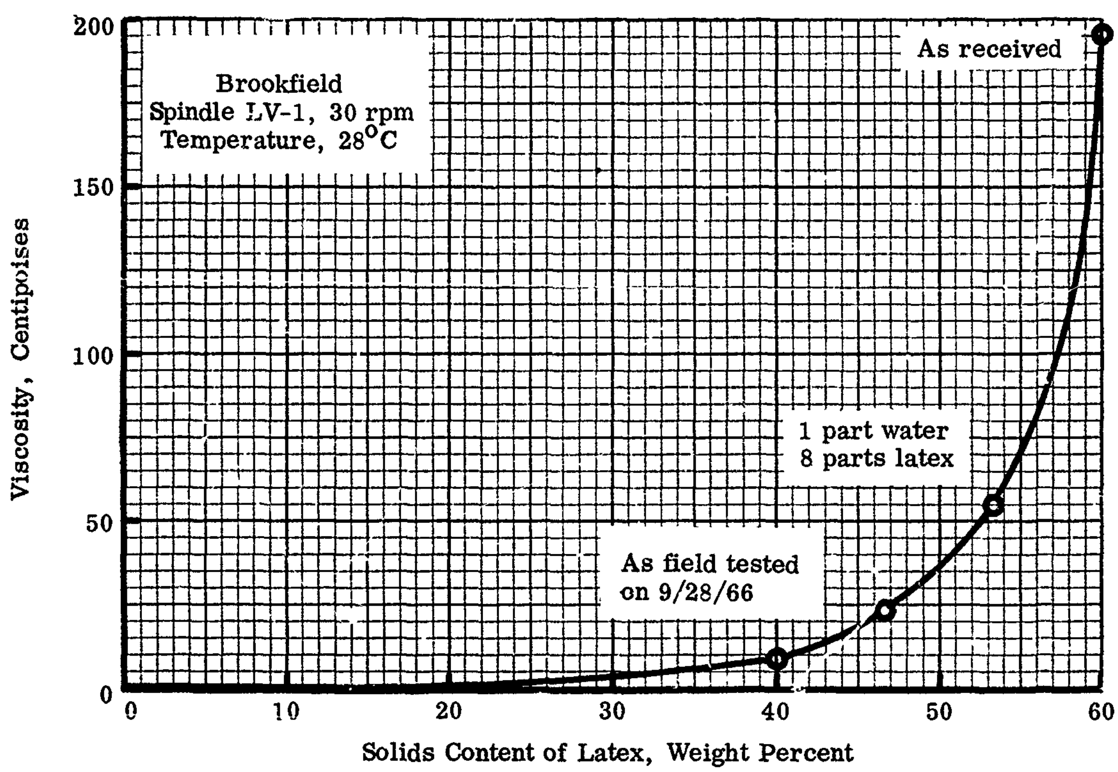

Figure 7. Effect of Concentration on Viscosity of Vultex 1-V-10G

While this study was conducted with only a limited number of coagulants it did show the range of effects that the coagulating agent can exert on the properties of the coatings. The problems of handling sulfuric acid caused its not being considered further.

37. At least six polymer latices gave coagulated coatings which clearly passed the laboratory screening tests. Of most interest were the prevulcanized rubber latices (Vultex 1-V-10F and 1-V-10G) Heveatex P1396 and P1397) with antioxidants for ozone and ultraviolet resistance. Vultex 3N10-U was an oil resistant neoprene latex which also satisfactorily coagulated on the surface of the sand soil and passed the test sequence. Two SBR latices (Darex 513L and 517L) passed the tests and were interesting from a cost standpoint (26 cents per pound of solids versus 42 cents per pound of solids for the prevulcanized rubbers).

2.2.2 Physical Properties of the Dust Control Films

38. Many of the surface films formed on the samples of soil used for the laboratory screening tests were used as the source of films for tensile test specimens, as described in Section 2.1.2. Table IV in the Appendix summarizes the results obtained from these tests. It should be noted that when full penetration of the dust control agent took place (for example, in sand), the maximum tensile strengths of the coherent cover were of the order of 2 lb per 1/2 inch width of film and the elongation at break was of the order of 100 to 300 percent. When a nonpenetrating coherent surface film was formed, these figures increased to strengths of up to 20 lb per 1/2 inch width of film and 600 to 750 percent elongation, for coating weights of 1.14 to 1.53 lbs per square yard. Penetrating materials yielded thicker films, as these films contained soil particles as well as the polymer.

2.2.3 Accelerated Aging Studies

39. It is of interest to determine the resistance of the coating solutions and emulsions to aging on storage and to obtain a measure of the degradation of coatings on aging.

a. Aging of coating solutions and emulsions. The storability requirements for any dust control agents are rather severe (open storage during humid, tropical conditions for three years). In evaluating candidate materials from the standpoint of storage, the change in viscosity of a solution or emulsion with aging gives a good measure of its degradation, and of the difficulties from this source which may be expected to be encountered during application. Accelerated aging tests were performed by measuring the viscosity of a compound with a Brookfield viscometer initially and at different time exposures to 50°C ambient temperatures (122°F). Table V in the Appendix provides a summary of the results obtained for urea resin solutions and three latex systems. Table VI in the Appendix summarizes the effect of latex concentration on the aging of the latex system of greatest interest, Vultex 1-V-10. This latex aged slightly after 43 days at 50°C when tested at 60% by weight solids,

and was totally unaffected when diluted to 40% by weight solids. Probably slight dilution to 50 - 55% solids will suffice to ensure proper lifetime under the required storage conditions.

b. Aging of the dust control coatings. Several coatings formed from materials that passed the laboratory screening tests were evaluated from the viewpoint of their aging or weathering characteristics, according to the tests described in Section 3.1.2 (c).

40. The results of the heat aging tests are presented in Table VII of the Appendix. The neoprene (Vultex 3-N-10V) film gave the best performance in the heat aging study. It appears that vulcanization of the neoprene took place at this temperature, resulting in an actual increase in tensile strength. While tensile strengths in the prevulcanized rubber films dropped considerably during oven aging, the elongations remained above 700 percent.

41. The results from the ozone exposure test showed that only Vultex 3-N-10V (neoprene), Heveatex P-1396 and P-1397 (prevulcanized rubber with antioxidants) went through the entire period without breaking. Failure occurs faster in extended samples, indicating that coating shrinkage is undesirable since aging is more rapid in the stretched film produced by the shrinking of film anchored at random locations.

42. Tests of the effects of exposure to ultraviolet light were carried out by exposing samples of rubber strips in the Fade-O-Meter for a period of 72 hours. The results of the test showed that Vultex 3-N-10V (neoprene) Heveatex P-1397 (prevulcanized rubber) and Geon 576 (plasticized polyvinyl chloride) maintained good elongation and tensile throughout the test period. Geon 576 did not discolor during aging.

2.2.4 Limited Traffic Tests

43. Two preliminary tests of this nature were carried out in a 3 ft x 3 ft x 1 ft deep sand plot at Dynatech. The material evaluated, Vultex 1-V-10G, withstood automobile traffic at a 35 psi tire pressure within four hours of application. Such traffic caused ruts 2 - 3 " deep.

44. A test of Vultex 1-V-10F was performed at WES. The test arranged was a series of four 10 foot by 15 foot areas composed of the following soils: 1 inch layer of loose, dry silt, 3 inch layer of sand; compacted silt (slightly damp on surface); and compacted heavy clay. Two such series of beds were arranged so that tests could be made with both alum coagulant and zinc chloride coagulant. The film former used was 1-V-10F Vultex, Lot No. 67-702, a compounded natural rubber latex supplied by General Latex of Cambridge.

45. The solution of the latex was carried out with rough mixing by using gallon cans to dip from the latex barrel. A mixture of 2-3/4 gallons latex with 1-1/2 gallons water was prepared separately for each plot. The coagulant was mixed with water and the quantities of latex in diluted form and coagulant were arranged so that complete use would give 6 gallons of total fluids per 10 by 15 foot section. This corresponds to 1.38 latex per square yard, or 0.825 lb solids per square yard.

46. For application of the materials a gasoline engine-powered, centrifugal pump fed from open 5 gallon cans was used. This pump fed a slot-type spray nozzle, arranged on the end of a wand. The spray pattern furnished by this unit was fan-shaped and consisted of fairly coarse droplets. These droplets were more finely dispersed than normally achieved in a field distributor, but were coarser than the spray achieved in the laboratory. The rate of application and coverage depended on the operator's skill in directing the spray over the surface to be covered.

47. Approximately 5 minutes was consumed in the spraying of each fluid onto the four test sections. With the time required to flush the pump with water between applications, the total time for application to these areas was about 15 minutes. The test area with zinc chloride was laid down at 9:45 a.m. and the test area with alum was laid down at 10:45 a.m. The immediate impression was that the latex hold-out was better on the alum treated areas. Following the application to the zinc chloride treated areas it was concluded that an extra latex spray should be applied to the edges of this test area. At 2 p.m. tests were made by driving three vehicles over the test areas; a jeep, a 3/4 ton personnel carrier, and a 4 by 2, 2-1/2 ton truck. In both cases the lightest vehicle broke through the latex layer on the sand. The other areas withstood traffic of all vehicles. The latex penetrated the sand rather than forming a surface film.

48. The failure of the sand plots on the traffic tests can be directly attributed to the failure of the material to form an elastic surface film. One cause for this failure was the presence of a nonionic dispersing agent in Vultex 1-V-10F, which slows down the coagulation process. Another cause was the excessive dilution of the latex prior to spraying with the following implications:

a. The much reduced viscosity (10 centipoises at 40% solids versus 200 centipoises at 60% solids) resulted in faster flow into the sand, with the consequent increased penetration.

b. The dilute emulsion is much more stable, and therefore takes a longer time to coagulate.

c. The additional water, which had to be evaporated before the material achieved full strength, resulted in a weaker coating at the time of the tests.

d. The nature of the spray (at fair velocity) may have displaced some of the layer of coagulant previously deposited by disturbing the soil surface.

49. A technique for rapidly producing a coherent film is to apply a second spray of coagulant over the latex applied to the primary coagulant application. In a test performed at Dynatech, a slight spray of coagulant on top of the emulsion layer was found to set the film immediately, making it trafficable within a matter of minutes.

3. DISTRIBUTION SYSTEM DESIGN

50. One of the objectives of this program to develop a technique for alleviation of dust was the design and fabrication of a prototype simple liquid spray distribution system for applying formulations developed in this study. A schematic sketch of the supply and distribution system developed is shown in Figure 8. The system is an air pressurized device dispersing liquid coagulant and latex simultaneously through multiple nozzles to obtain rapid application of a wide applied pattern. The two primary components of this system are the pressurized latex and coagulant supply systems and the distribution system. These two components will be discussed separately in the following subsections.

51. There are two basic reasons for the selection of the system shown in Figure 8. First, the handling of latex requires a minimum of shearing action to prevent premature coagulation within the dispensing system. A pressurized system meets this requirement whereas a positive displacement pump does not, although the flows and pressures of interest would dictate the selection of a positive displacement pump under the circumstances of handling shear insensitive material. A hand carried system requires a relatively low level, steady flow (4 - 12 gpm) and an unvarying nozzle pressure to apply a uniform coating. The second factor determining the design was the desire to arrange a device allowing flexibility in the mode of use. A frame holding several nozzles dispensing coagulant and latex (present system 3 coagulant, 2 latex) can be hand carried by two men. Such a frame might also be mounted on the rear of a truck or modified tar sprayer and the sprays applied by moving such a truck slowly over the desired application pattern.

3.1 Pressurized Supply Component

52. The pressurized supply component as shown in Figure 8 consists of the following items listed with their required operating characteristics.

a. Air compressor

(1) 80 - 100 psi discharge pressure

(2) 10 SCFM* at compressor inlet conditions

b. Air regulators

(1) Latex tank: Regulate pressure to about 60 psi passing 7.5 SCFM flow

(2) Coagulant tank: Regulate pressure to about 50 psi passing 2.5 SCFM flow

c. Supply tanks: Working pressure to 100 psi

(1) Latex tank: About 30 gallon capacity

(2) Coagulant tank: About 10.0 gallon capacity. Both tanks with a liquid removal tube to bottom of tank.

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*SCFM refers to 14.7 psia and 70°F.

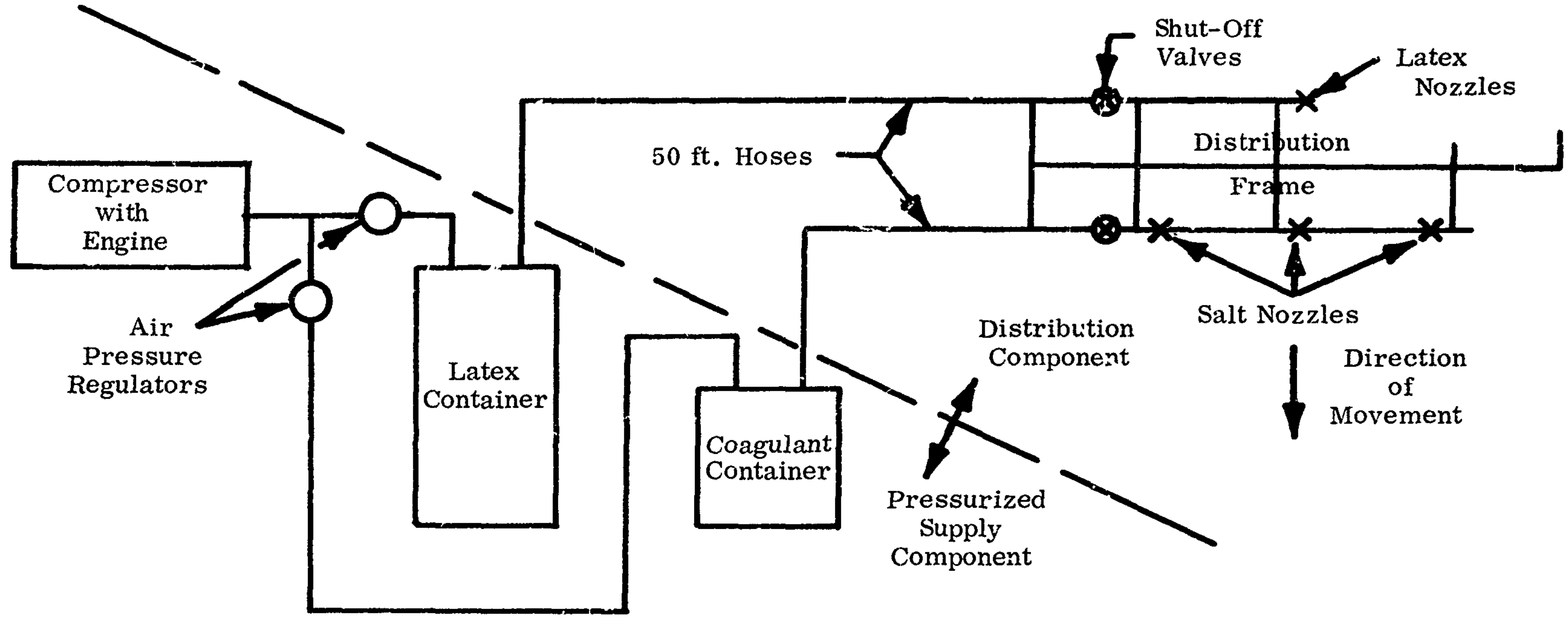

Figure 8. Schematic Diagram of Supply and Distribution System

Instead of an air compressor, a pressurized bottle supply could be used with the proper regulator to pressurize the supply tanks whenever small experimental spray tests are desired.

53. Dynatech Corporation did not deliver the pressurized supply component as outlined above to WES because such equipment is already available at the WES.

3.2 Distribution Component

54. The distribution component of the device shown schematically in Figure 8 is shown in more detail in Figure 9. The purpose of this component is to provide a portable frame which properly positions the coagulant and latex nozzles so that the nozzles will deliver fluid to cover a strip of soil 10 to 11 feet wide. Carried by two men, the frame is intended to be moved slowly over the soil so as to lay down a continuous uniform coating of coagulated latex. As the two sets of nozzles are moved along the soil is first soaked with the coagulant and then the latex is laid down on top of the coagulant. The following parts make up the distribution system:

a. Three coagulant nozzles: These are Spray Systems Full-jet nozzles No. 1/8 GGSS6SQ which spray in a square pattern. Each nozzle will uniformly spray a four foot square when held about 3 feet off the ground. (1.1 GPM each at 40 psi for water)

b. Two latex nozzles: These are Spray Systems Floodjet nozzles No. 3/8 KSS30 which spray in a thin wide strip. Each nozzle will spray a strip about 8 feet wide when held about three feet off the ground. (5.5 gpm each at 40 psi for water)

c. PVC pipe: To carry liquid into frame and to nozzles
1" nominal pipe - coagulant
1 1/2" nominal pipe - latex
These large diameters are required for low pressure drop.

d. Pressure gauges: To measure nozzle supply pressures for control of liquid flows.

e. Two plastic ball valves: For rapid starting and stopping of both liquid flows.

f. Hose: Latex 1 1/2" I.D. light weight fire hose
Coagulant 1" I.D. light weight fire hose.
50 feet of each supplied.

55. The frame holding the PVC pipes together was made from 1" nominal aluminum pipe to provide a light weight but fairly rigid structure. To form the rigid pipe intersections, slip-on aluminum pipe fittings with set screws were used.

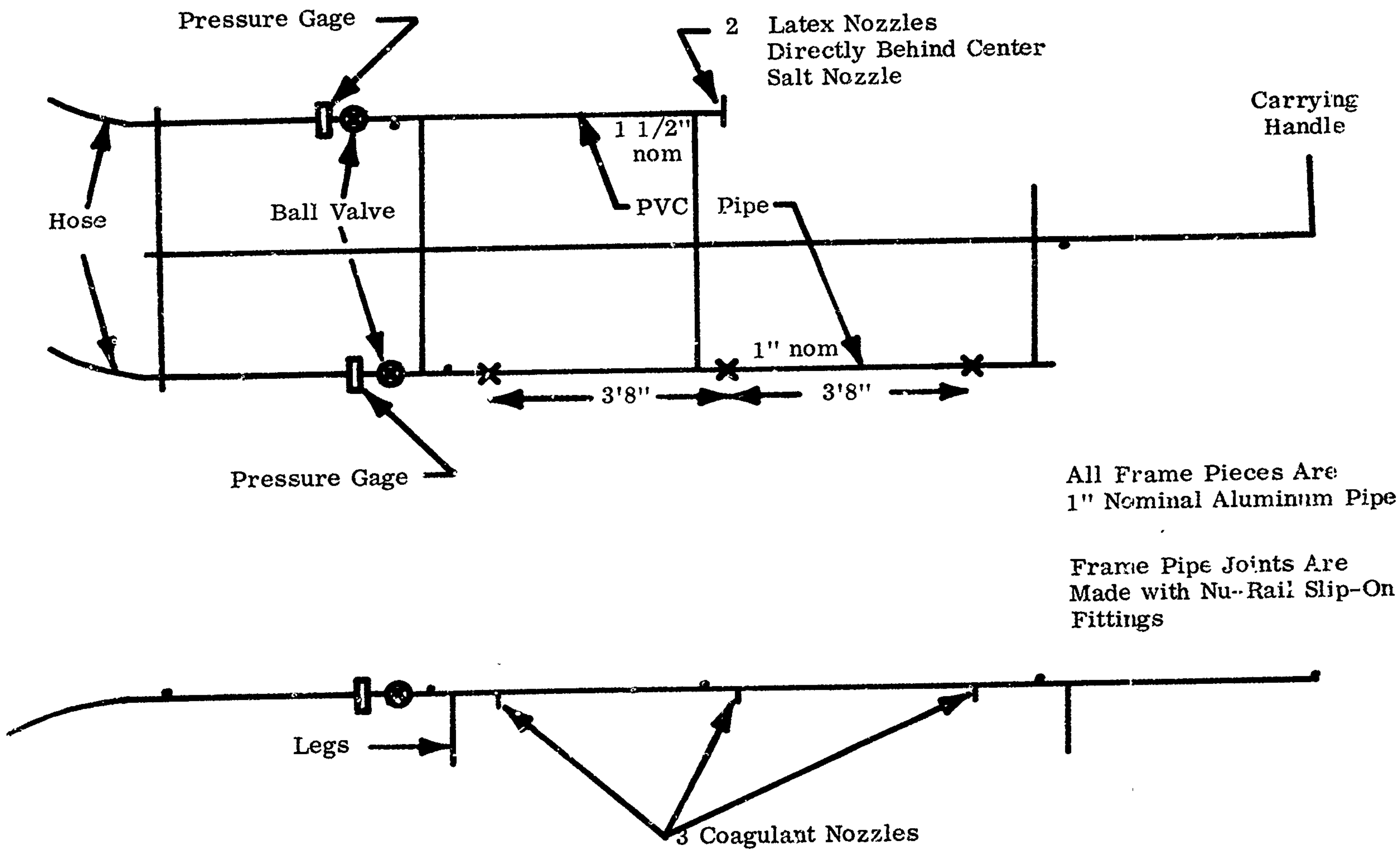

Figure 9. Detailed Diagram of Distribution System

Use of these fittings permits rapid assembly and light weight. The frame consists of the following members:

a. Three cross pieces attaching the two PVC pipes to the center aluminum pipe.

b. Seventeen foot aluminum center pipe.

c. One cross piece for hose support to prevent bending at the threaded plastic valve joints.

d. Three legs to allow the frame to be set on the ground while not in use without damaging nozzles.

e. One extra cross handle to help hold frame level.

f. Thirteen slip-on joint fittings.

This kind of construction and assembly gives flexibility that will allow adaptation of this frame to truck mounting or different hand carrying schemes. The distribution frame could easily be adapted to supply a second coagulant pipe following the latex, if this proves desirable.

56. The distribution system is operated as follows:

a. Filling and start-up. The hoses and PVC piping can be filled at low or high pressure. When the liquid flow pattern from the nozzles becomes uniform, the ball valves are closed and the system is ready for spraying. The recommended flow rate ratio is 2.3 pounds of latex per pound of liquid coagulant which accounts for the fact that the coagulant sprays a larger area. The pressure required to force the coagulant through the nozzle will range from 20 to 40 psi. The pressure required to force the latex through the nozzle will range from 20 to 60 psi. These pressures are set according to the gauges mounted directly on the distribution system. The pressures required in the container will be 10 to 35 psi higher depending on the liquid viscosities, the size of the container siphon pipes, the shape of the hose, and atmospheric temperature effects mainly on viscosity. Before field spraying with new formulations the proper pressure settings for the desired flows should be determined by test measurement to account for the effects listed above.

b. Area spraying. To spray the soil, the coagulant flow is turned on first to wet the initial area. Then, as the latex nozzles move over the wet area, the latex valve is opened. The frame should be held about 3 feet off of the ground. The height should be adjusted so that the spray from the individual coagulant nozzles overlap at impact on the soil so as to give a uniform soaking. The frame should be moved at the rate of about 0.7 feet per second. This speed will yield coatings in the 1 - 2 lb/square yard range. The correct speed can be determined by watching the latex coating. If the dark color of the soil shows through the latex, the frame is being moved too fast. If puddles of latex begin to form the frame is being moved too slowly. The operators must therefore watch both sprays

to determine the correct height and speed. A 60 foot strip of the test soil can be covered in about 1-1/2 minutes of spraying.

c. Shut down and flushing. When the end of the soil plot to be sprayed is reached the ball valves are closed to turn off the flow. The latex container should be large enough to prevent air from entering the hose before the end of the spraying. The reason for this is that in a matter of minutes the latex film remaining on the hose surface will form a scum in the presence of air. Such solid material may come loose during subsequent tests and clog the nozzles. A 30 gallon latex container and 7-1/2 to 10 gallon coagulant container are large enough for spraying a 10 foot by 60 foot plot. If air does enter the latex hose, it should be flushed with water as soon as possible. When spraying is finished, all of the liquid containing equipment and hoses should be thoroughly flushed with water.

3.3 System Application to Field Unit

57. The present two-man distribution system shown in Figure 8 will permit coverage of 1000 sq yd in about 22 minutes of spraying time. This allows 38 minutes for other operations if application at the rate of 500 sq yd per hour per man is to be attained. A hand carried system supplied from 55 gallon drums of latex would require the following characteristics for two men to handle 4 to 5 drums of latex per hour.

a. Latex supplied to field in 55 gallon pressurizable aluminum drums (MIL-D-4303A) laid out in the pattern the spray system is to use.

b. Coagulant supplied to the field in 10 or 20 gallon containers to be emptied into a portable 20 gallon container of the spray system.

c. Portable gasoline driven air compressor (MIL-C-3925D) or large unit at the side of the field to be used as air pressure source.

d. Quick disconnect cap for latex drum with syphon pipe and air inlet mounted through it.

e. Quick disconnect lid for coagulant container to insure rapid transfer of liquid from supply drum to pressure tank.

f. Coarse strainer (1/32" holes) on latex siphon pipe inlet to remove large latex lumps and foreign particles.

g. Battery operated bell or light system to indicate low latex level in drum and allow operator to prevent air from entering hose.

h. Valve on both ends of each hose to hold liquid in while transferring to next container.

58. The spraying operation must be well organized to minimize

wasted time and effort if two men are to cover 1000 square yards per hour when supplied with 55 gallon latex drums. Spraying from a large capacity tank truck with a nozzle frame would easily permit covering more than 500 square yards per man hour. The pattern in which distribution is carried out must be arranged so as to avoid treading on wet coating or dragging hoses through it.

59. The distribution frame of the present design weighs about 75 pounds including liquid and supported hose. This is not a minimum weight system. A configuration which would permit weight reduction and increase the rigidity of the device is one in which the latex and coagulant pipes are supported one above the other, connected by straps to handles at each end. A single latex pipe projecting perpendicular to the supply pipe would permit positioning the latex nozzles in the same relationship to the coagulant nozzles shown in Figure 8.

60. Two other important subjects for design consideration in addition to low system weight are delivery hose pressure drops and nozzle spray patterns. These two topics are related in that the maximum delivery hose pressure loss must be less than the difference between maximum supply pressure and minimum nozzle pressure operation. The delivery line pressure loss consists mainly of fluid frictional losses but also includes siphon pipe inlet losses, expansion losses to large hose, turning losses around elbows and hose bends, and contraction losses at the nozzles. All of these losses are proportional to the square of the fluid velocity in the pipes. The fluid velocity is sufficiently low in the system described here that these secondary pressure losses can be neglected. The flow frictional losses calculated on the basis of pipe friction factor data are strongly influenced by fluid viscosity as well as fluid velocity. The standard equation for pipe friction pressure loss and three curves for absolute viscosity levels of 1, 100, and 300 centipoises are shown in Figure 10. For long delivery lines, large diameter hoses are required. For short sections small diameter pipes can be used. The latex under consideration may range in viscosity level from 50 to 300 centipoises depending on concentration and temperature conditions. This dictated the choice of a 1-1/2"diameter 50 foot hose for the present application.

61. The nozzles to apply the latex and coagulant liquids to the soil could be of the air atomization type or straight liquid spray type. The air atomization type was not considered in the present design because:

a. A large air compressor would be needed to supply air to a large number of nozzles.

b. Air atomization spray patterns are generally small angle, and therefore a large number would be needed.

c. The mist formed would be easily carried by the wind.

Straight liquid spray nozzles are available in many spray pattern shapes (square, circular, annular, thin strip). However, the viscosity of the latex tends to destroy the pattern uniformity and therefore make some nozzle types unusable. The nozzle spray pattern characteristics that must be considered are:

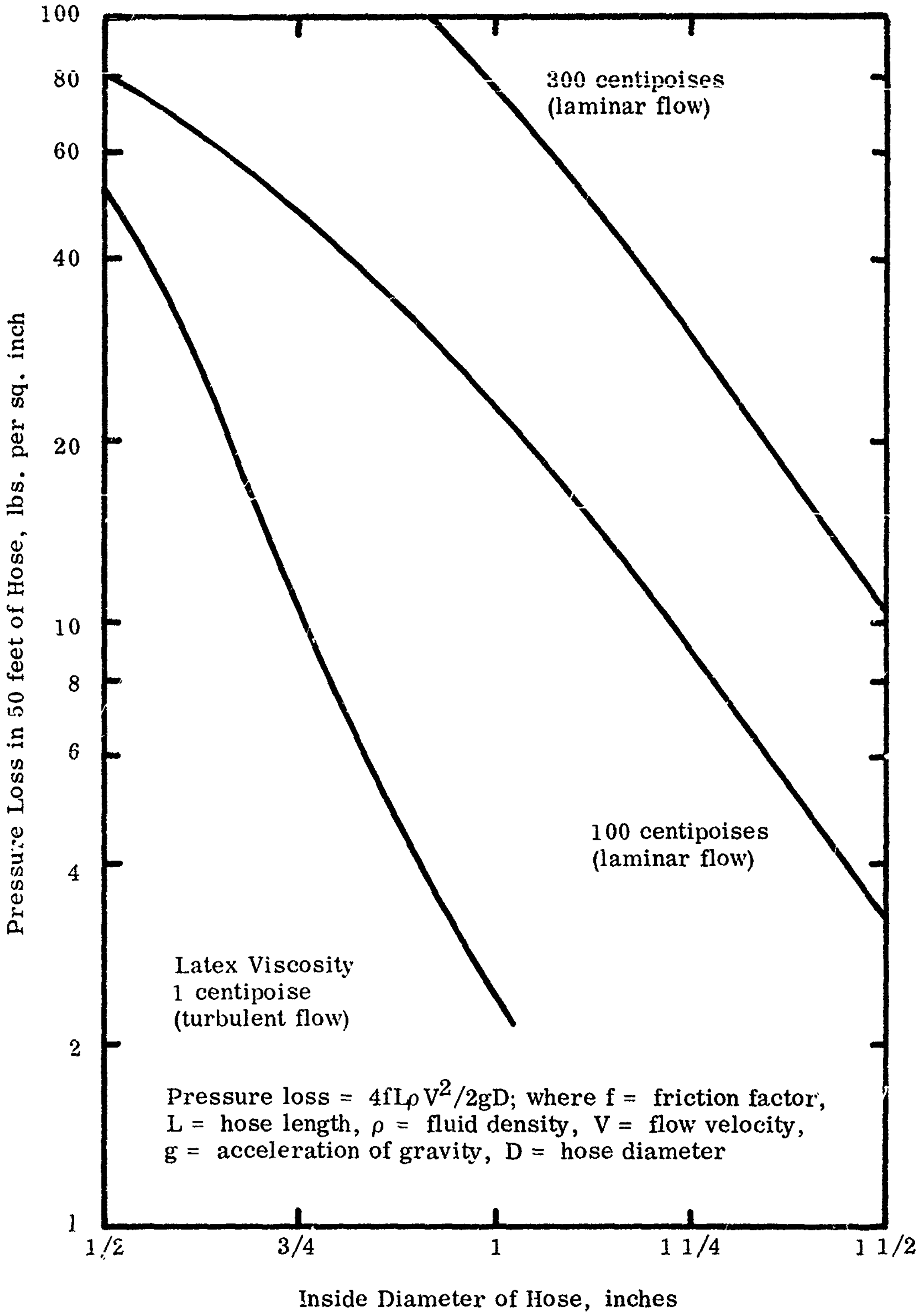

Figure 10. Latex Line Pressure Losses
(Latex flow rate, 11 gallons per minute;
Roughness of hose, 0.001 inches)

a. Spray uniformity over area

b. Drop size of spray

c. Impact of liquid on soil

d. Shape of pattern

e. Size of pattern

f. Nozzle sensitivity to clogging

The nozzles selected for the coagulant spray in the distribution device delivered to WES supply a narrow angle (70°) square pattern. The spray is uniform, easy to overlap for good area coverage and gives a fairly fine spray to easily wet all soils without disturbing them. The square pattern and slow movement allows the soil to be soaked for 3 to 5 seconds so that any cracks that form on initial wetting are resoaked. The latex nozzles selected lay down the liquid in two long narrow strips of fairly coarse drops but with uniform coverage. The latex nozzles are of the floodjet type which have no internal vanes making them clog resistant and easily cleaned. A working pressure of about 40 psi is used for both nozzles to obtain reduced drop sizes within the nozzles selected.

4. LOGISTICAL FACTORS

4.1 Availability of Natural Rubber Latex Near Theater of Operations

62. The utility of natural rubber latex as a material for preparing a dust cover makes it of interest to examine the possibility of procuring the latex near the theater of operation. Since the largest production of natural rubber latex is in the Far East, especially Malaysia and even South Vietnam, the supply problem in obtaining the latex might be greatly simplified and costs reduced by local procurement. Latex is produced from the rubber tree at 30 to 45 percent solids. After collection at the plantation it is essential that it be treated chemically to preserve it from bacterial decomposition. This preservation is accomplished by adding ammonia to the latex. The amount added is generally of the order of magnitude of 1/2 percent NH_3. Once preserved with ammonia the latex may be held for long periods of time and shipped by rail or sea without danger of putrefaction or coagulation.

63. It is possible to concentrate latex before shipment in order to reduce the cost of shipment. Various techniques are used to increase the solids content of latex from the level obtained from the tree up to at least 60 percent solids and by special techniques somewhat higher. The earliest procedure for such concentration was "creaming", in which the particles of latex rise in the aqueous dispersion just as cream does in milk. The rate of creaming can be accelerated by adding substances which increase the effective size of the latex particles so that the buoyant forces increase. The most common procedure is to concentrate the latex by centrifugation. In the process of centrifugation the basic mechanism of concentration is the same as creaming except that the force exerted on the particles is many times multiplied in the centrifuge. In centrifugation it is not necessary to add materials to increase the particle size. There are other processes for concentration of latex such as evaporation, filtration, and electrical procedures, but the principal one in use is centrifugation.

64. The processes of stabilization by the addition of ammonia and the concentration by centrifugation are widely practiced in the rubber producing areas of the Far East. The product so produced is shipped all over the world, and there is no basic reason why this product could not be obtained directly from plantations in Southeast Asia in drums. The product could be used directly in the procedures developed in this program but the work carried out indicates that such production of latex could be improved. Specifically it would be desirable to:

1. Adjust the viscosity of the latex
2. Add anti-oxidant materials
3. Add tack reducing agents
4. "Vulcanize" the latex particles to a slight degree

Although these modifications of latex are not necessarily now being made in the rubber producing areas, there is no basic reason why arrangements could not be made to carry them out in the Far East. Such arrangements might greatly simplify the supply and logistic problem of providing dust treatment in the theater of operations.

65. It should also be pointed out that natural rubber latex in the condition drawn from the tree could be used expeditiously when military operations are conducted within short distances of rubber plantations. Unpreserved latex within a few hours of gathering would be satisfactory for application and could provide dust palliation. The chief drawbacks of such a dust cover would be a relatively short lifetime before degradation and a tendency toward tackiness.

4.2 Critical Storage Conditions

66. All of the polymer solutions or latexes examined as dust treating agents in this work are aqueous systems and therefore subject to freezing if exposed to temperatures below 32°F for sufficient time. If drums or tanks loaded with these materials are expected to be exposed to subfreezing environments then suitable insulation or provision of heat may be required. If the shipping distance is short, there may not be sufficient time for cooling of the entire mass of material to near freezing, but for longer distances protection will be required. If latex is frozen, it may under some circumstances be recovered and used by allowing it to thaw slowly. The danger is great, however, that the freezing will cause agglomeration to the extent that the latex is no longer usable.

67. The upper temperature to which these materials may be exposed is determined by their thermal sensitivity, the possibility of evaporation and subsequent concentration, or to the loss of volatile preserving agents such as ammonia. If a quantity of latex is protected from evaporation or loss of volatile stabilizers, the upper temperature limit to which it may be exposed is often quite high. In Section 2.2.3 above the results of accelerated aging tests of latex were reported. These tests indicated that latex at concentrations somewhat more dilute than the usual concentration of commerce was quite stable.

68. At room temperature the natural rubber latex of commerce (60%) is commonly quoted to be storable for six months. In practice a year's storage may be attained. The effect of dilution on room temperature storage was not tested but there is no reason to expect that the improvement in aging at high temperature would not be obtained in lower temperature storage. Neoprene latex has been stored at Dynatech for 1-1/2 years at room temperature without deterioration.

5. CONCLUSIONS

69. Out of the dust control systems studied, elastomer emulsion systems used in conjunction with a suitable coagulating agent offer considerable promise as dust control agents for military purposes. They can be applied on a wide range of soils with relative simplicity.

70. The feature of chemical coagulation of the emulsions is a very important one, as it provides control over penetration of the dust control agents into the soil as well as on their setting characteristics.

71. There is a great range of elastomer systems that could, with proper formulation, be potentially capable of meeting most of the operational requirements for dust control agents.

72. The urea-based systems, because of the lack of flexibility of their applied films, were found to be generally unsuitable for the desired function.

73. Of the latex systems examined in this study, Vultex 3-N-10V and Heveatex P-1397 were found to have the best capability as all around dust control coating materials.

6. RECOMMENDATIONS

74. The short time schedule of the present program imposed the use of readily available, proprietary formulations for evaluation as dust control agents. These formulations were not especially designed for their use as dust control agents. Better results can be obtained with formulations prepared with the specific application in mind, and it is recommended that specific formulations for this use be developed, which take into account the requirements for storability, film properties, application and aging.

75. It is a distinct possibility that indigenous products such as Hevea rubber latex, presently produced in Malaysia and South Vietnam, could be suitably formulated at the site of usage or distribution into acceptable dust control agents. The favorable logistic implications of using such a material make it desirable to investigate natural rubber latex formulations and the extent of and practicability of the modifications required.

76. The proper spray pattern and spray sequence and amount of latex and coagulant have a critical effect on formed film properties. Further investigation of this general problem should go parallel to the latex formulation investigation and testing.

77. Storability and formed film aging tests should be carried out in a more thorough fashion to allow a realistic evaluation of the material's potential for fulfilling QMR requirements.

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APPENDIX

I SUMMARY OF LABORATORY TESTS OF AGENTS FOR DUST CONTROL

Test	Soil Type	Dry Soil Density lb/ft^3	Moisture Content, wt, %	Coating	Coating Wet Weight Applied, lb/yd^2	Test* Air 1	Rain	Air 2	Air 3	Remarks
1	Beach Sand	96.9	< 1	Pacific N-748-N** Phosphoric Acid	6.02	P	P	P	P	Rigid Porous
2	Potters Flint	55	< 3	" "	6.09	P	P	P	P	Rigid, non-porous
3	" "	90	18	" "	4.48	P	P	P	P	" "
4	" "	"	12.8	" "	5.21	P	P	P	P	" "
5	" "	"	"	" " plus 1% Renex 35	5.21	P	P	P	P	" "
6	" "	"	"	Pacific N-748-N*** Phosphoric Acid	3.68	P	P	P	P	" "
7	" "	"	"	" "	1.95	P	P	P	P	" "
8	" "	"	"	Pacific N-748-N**** Everflex GT Phosphoric Acid	1.31	P	P	P	P	Slightly flexible Non-porous
9	" "	"	"	Everflex GT (27.6% solids)	1.47	P	P	P	P	Flexible Non-porous
10	" "	"	"	Neoprene 750	1.69	P	P	P	P	Flexible Non-porous

* Test Procedures (Ref. 6) are described in Section 2.1.2. Passage or failure of the tests indicated as follows: P - passed, f - failed.

** Composition: 150 ml Pacific N-748-N diluted with 150 ml water plus 8.25 gm 55% (by weight) phosphoric acid. Renex addition based on undiluted resin.

*** Composition like tests 1 - 5 plus addition of 1.2 gm $(NH_4)_2CO_3$ and 12 gm urea.

**** Composition: 50 ml Pacific N-748-N and 50 ml Everflex GT diluted with 100 ml water plus 2.75 gm 55% phosphoric acid.

Test	Soil Type	Dry Soil Density lb/ft3	Moisture Content, wt. %	Coating	Coating Wet Weight Applied, lb/yd2	Test Air 1	Test Rain	Test Air 2	Test Air 3	Remarks
11	Beach Sand	97	< 1	Everflex GT (27.6% solids)	1.61	P	P	P	P	Flexible, penetration, non-porous
12	" "	"	"	Neoprene 750	1.61	P	P	P	P	" " "
13	" "	"	"	Pacific N-748-N* Phosphoric Acid	1.76	P	P	P	P	Rigid, penetration, porous
14	Potters Flint	58	< 3	Everflex GT (27.6% solids)	1.76	P	f	-	-	
15	" "	"	"	Neoprene 750	1.54	f	-	-	-	
16	" "	"	"	Pacific N-748-N* Phosphoric Acid	1.35	f	-	-	-	
17	" "	54	"	" "	4.47	P	P	P	f	
18	Clayey Silt	38**	2	Everflex GT (27.6% solid)	1.54	f	-	-	-	
19	" "	"	"	Pacific N-748-N* Phosphoric Acid	1.46	P	f	-	-	
20	" "	"	"	" "	3.65	P	f	-	-	
21	" "	90	"	" "	1.53	P	P	P	P	Rigid, non-porous
22	" "	124	12	" "	1.31	P	P	P	P	" "
23	" "	91	16	" "	1.76	P	P	P	P	" "

* Same composition as that used in Test 1.

**Density measured in sifted, uncompacted state as tested.

Test	Soil Type	Soil Density lb/ft^3	Moisture Content, wt.%	Coating	Coating Wet Weight Applied, lb/yd^2	Test: Air 1	Test: Rain	Test: Air 2	Test: Air 3	Remarks
24	Potters Flint	58	<3	dual spraying 8% phosphoric acid and Neoprene 750*	2.04	f at 55 psf	-	-	-	Intermixed the acid spray with the latex spray. A porous coagulated coating formed that could not cover the surface cracks.
25	Clayey Silt	38	2	" " "	1.47	f at 55 psf	-	-	-	" " "
26	Beach Sand	97	<1	" " "	1.83	f at 55 psf	-	-	-	
27	Clayey Silt	38	2	water	0.67					
				dual spraying Neoprene 750 8% phosphoric acid*	3.14	f at 55 psf	-	-	-	" " "
28	" "	38	2	water	0.73					
				Neoprene 750	2.19					
				8% phosphoric acid	0.73	P	P	P	P	a good rubber surface coating
29	" "	"	"	8% phosphoric acid	0.81					
				Neoprene 750	1.46					
				8% phosphoric acid	0.22	P	P	P	-	
30	" "	38	2	8% phosphoric acid	0.36					
				Neoprene 750	0.36					
				8% phosphoric acid	0.36					
				Neoprene 750	0.81					
				8% phosphoric acid	0.44					
				Neoprene 750	0.73					

*Approximate proportions: 3 volumes of latex per volume of 8% phosphoric acid.

Test	Soil Type	Soil Density lb/ft^3	Moisture Content, wt. %	Coating	Coating Wet Weight Applied, lb/yd^2	Test: Air 1	Test: Rain	Test: Air 2	Test: Air 3	Remarks
30	Clayey Silt	38	2	8% phosphoric acid Neoprene 750 8% phosphoric acid	0.22 0.44 0.07	P	P	P	P	a cloudy somewhat tacky rubber coating
31	" "	"	"	8% phosphoric acid Geon Vinyl 576 8% phosphoric acid	1.24 2.24 1.02	P	P	P	P	coating contracted a little from the walls of the container.
32	" "	"	"	8% phosphoric acid Nitrile Latex 1512 8% phosphoric acid	0.73 1.97 0.44	P	P	P	-	" " "
33	" "	55	"	water Pliovic 400 8% phosphoric acid	0.95 3.08 0.37	P	P	f at 30 psf	-	a coating with low elongation
34	" "	"	"	water Neoprene 950 8% phosphoric acid	1.04 1.61 0.29	P	P	P	P	coating had low elongation and showed signs of aging badly.
35	" "	55	2	8% phosphoric acid Neoprene 750 8% phosphoric acid	0.66 1.90 0.37	P	-	-	-	
36	" "	"	"	N-748-N and phosphoric acid*	1 32					The urea formaldehyde and acid was mixed continuously in the spray nozzle.

*Composition: 300 ml N-748-N diluted with 200 ml water in stream 1, 8% phosphoric acid in stream 2;
Proportions: 2 volumes stream 1 per volume of stream 2.

Test	Soil Type	Soil Density lb/ft^3	Moisture Content, wt %	Coating	Coating Wet Weight Applied, lb/yd^2	Test: Air 1	Test: Rain	Test: Air 2	Test: Air 3	Remarks
36	Clayey Silt	55	2	N-747-N and phosphoric acid	1.61	-	-	-	-	The first coating set for 18 min. before applying second. The sample was not coated in the cracked areas and would have failed the air blast
37	" "	"	"	8% phosphoric acid	1.02					
				N-748-N and phosphoric acid (Compositionlike Test 36)	2.20	-	-	-	-	poor coating in cracked areas
38	" "	"	"	8% phosphoric acid	0.95	(tested 1-1/4 hrs after coating)				
				Vultex 1-V-10 (60% solids)	2.12	P	P	P	P	an excellent tack-free coating with very good rubber properties
39	" "	"	"	Vultex 1-V-10 (60% solids)	2.56	(tested 3-1/2 hrs after coating)				" " "
				8% phosphoric acid	0.73	P	P	P	P	
40	Beach Sand	97	< 1%	8% phosphoric acid	0.73					
				Vultex 1-V-10 (60% solids)	1.98	P	P	P	P	" " "
41	Potters Flint	55	<3	8% phosphoric acid	0.66	P	P	P	P	Excellent complete rubber coating
				Vultex 1-V-10 (60% solids)	2.42					
42	Clayey Silt	"	2	water	1.02					
				Vultex 1-V-10 (60% solids)	2.20	P	P	P	P	" " "
43	" "	90	14	8% phosphoric acid	1.02					
				Vultex 1-V-10 (60% solids)	1.68	P	P	[illegible]	P	" " "

Test	Soil Type	Soil Density lb/ft^3	Moisture Content, wt.%	Coating	Coating Wet Weight Applied, lb/yd^2	Test Air 1	Test Rain	Test Air 2	Test Air 3	Remarks
44	Potters Flint	90	12	8% phosphoric acid 1-V-10 (60% solids)	0.73 2.70	P	P	P	P	Excellent complete rubber coating
45	Clayey Silt	90	14	8% phosphoric acid 1-V-10 (60% solids)	1.61 1.98	P	P	P	P	" " "
46	" "	"	"	1-V-10 (60% solids)	2.27	P	P	P	P	a weaker coating than 45 and deeper penetration
47	Potters Flint	"	12	8% phosphoric acid 1-V-10 (60% solids)	0.73 1.17	P	P	P	P	an excellent rubber surface coating
48	Clayey Silt	"	14	8% phosphoric acid 1-V-10 (40% solids)	1.02 2.05	P	P	P	-	coat not as strong as a coating prepared from 60% solid latex
49	Repeat of 48									
50	Clayey Silt	55	2	8% phosphoric acid 1-V-10 (40% soilds)	0.89 2.20	P	P	P	-	
51	Beach Sand	97	<1	8% phosphoric acid 1-V-10 (40% solids)	1.02 1.76	P	P	P	-	a good surface not quite as good as when a 60% solid latex is used.
52	" "	"	"	1-V-10 (40% solids)	3.30	P	P	P	-	very weak coating with complete impregnation

Test	Soil Type	Soil Density lb/ft^3	Moisture Content, wt.%	Coating	Coating Wet Weight Applied, lb/yd^2	Test: Air 1	Test: Rain	Test: Air 2	Test: Air 3	Remarks
53	Clayey Silt	55	2	10% tartaric acid 1-V-10 (40% solids)	0.66 2.05	P	f	-	-	
54	Beach Sand	97	<1	10% tartaric acid 1-V-10 (40% solids)	0.73 4.30	f at 55psf	-	-	-	
55	Repeat of 54									
56	Beach Sand	97	<1	30% calcium nitrate 1-V-10 (40% solids)	1.02 2.05	P	P	P	-	good coagulation with little penetration. Initial coating strength only fair.
57	Clayey Silt	55	2	30% calcium nitrate 1-V-10 (40% solids)	0.73 2.20	P	P	P	-	weak coating
58	" "	90	2*	30% calcium nitrate 1-V-10 (40% solids)	1.10 1.54	P	P	P	-	
59	Clayey Silt	55	2	8% phosphoric acid 1-V-10 (40% solids)	0.81 3.44	P	P	P	-	
60	Beach Sand	97	<1	8% phosphoric acid natural rubber latex (44% solids)	0.81 3.30	P	P	P	-	a coating with only fair strength. coating impregnated sand
61	" "	"	"	30% calcium chloride 1-V-10 (40% solids)	0.73 2.78	f at 50 psf	-	-	-	Deep penetration of latex
62	" "	"	"	30% zinc nitrate 1-V-10 (40% solids)	1.17 1.46	P	P	P	f	coating degraded when subjected to sun lamps
63	" "	"	"	15.6% sulfuric acid 1-V-10 (40% solids)	1.17 1.54	P	P	P	f	" " "

*Test 58 performed on same material used in Test 57, but compacted.

Test	Soil Type	Soil Density lb/ft^3	Moisture Content, wt. %	Coating	Coating Wet Weight Applied, lb/yd^2	Test: Air 1	Test: Rain	Test: Air 2	Test: Air 3	Remarks
64	Clayey Silt	55	2	15.6% sulfuric acid 1-V-10 (40% solids)	1.10 1.39	P	P	P	P	
65	Beach Sand	97	<1	water Resymul VA 57A-2-1 (PVA)	0.51 2.49	P	f	-	-	
66	" "	"	"	8% phosphoric acid Dow Latex 358	1.17 1.15	P	f	-	-	
67	" "	"	"	3.7% hydrochloric acid 1-V-10 (40% solids)	1.02 1.90	f at 50 psf	-	-	-	very weak coating
68	Clayey Silt	90	14	3.7% hydrochloric acid 1-V-10 (40% solids)	1.10 1.32	P	P	-		
69	Beach Sand	97	<1	30% nickel chloride soln. 1-V-10 (40% solids)	1.17 2.05	f at 50 psf	-	-	-	Excellent coagulation but coating was weak
70	" "	"	"	13.8% phosphoric acid 1-V-10 (40% solids)	0.88 1.83	-	-	-	-	
71	" "	"	"	22.5% phosphoric acid 1-V-10 (40% solids)	1.24 2.05	-	-	-	-	
72	" "	"	"	6.6% phosphoric acid 1-V-10 (40% solids)	1.10 2.42	-	-	-	-	The coatings in 70, 71 and 72 appeared similar and not as good as the 60% solid system.
73	Clayey Silt	90	14	13.8% phosphoric acid 1-V-10 (40% solids)	1.10 1.17	-	-	-	-	

Test	Soil Type	Soil Density lb/ft^3	Moisture Content, wt.%	Coating	Coating Wet Weight Applied, lb/yd^2	Test Air 1	Test Rain	Test Air 2	Test Air 3	Remarks
74	Beach Sand	97	air dried	8% phosphoric acid (0.4% carbopol 941) 1-V-10 (40% solids)	0.66 2.12	-	-	-	-	
75	" "	"	"	50% DDBSA in acetone 1-V-10 (40% solids)	0.59 2.26	-	-	-	-	very poor, crack filled coating
76	" "	"	"	8% phosphoric acid (0.4% Benax 2A1) 1-V-10 (40% solids)	1.02 3.00	-	-	-	-	The surface active agent allowed the coating to penetrate deeper yielding a weaker coating.
77	" "	"	"	8% phosphoric acid (20% ethylene glycol) 980 XL Latex (Geon)	0.95 2.20	-	-	-	-	Excessive penetration of latex
78	" "	"	"	8% phosphoric acid Neoprene 750	0.88 2.20	-	-	-	-	" " "
79	" "	"	"	8% phosphoric acid Neoprene 400	1.10 3.44	-	-	-	-	" " "
80	Sand	-	washed and air dried	8% phosphoric acid Vultex 1-V-10 (60% solids)	0.6 2.5					Prepared a hole (1 yd x 1 yd and 3 inches deep) in the ground and filled with sand. Sprayed the acid and then the latex. After 2-3/4 hours at 85°F. A car could drive over the coating without picking it up or tearing it.

Test	Soil Type	Soil Density lb/ft^3	Moisture Content, wt. %	Coating	Coating Wet Weight Applied, lb/yd^2	Test Air 1	Test Rain	Test Air 2	Test Air 3	Remarks
81	Beach Sand	97	air dried	8% phosphoric acid Vultex 1-V-10 (60% so solids)	0.73 2.63	-	-	-	-	Excessive penetration of latex.
82	" "	"	"	8% phosphoric acid Vultex 2-V-109-A	0.66 2.34	P	P	P	-	a great deal of latex penetration, a weak coating after 4 hours
83	" "	"	"	8% phosphoric acid Neoprene 750 (raised viscosity to 270 cp with sodium carboxymethyl cellulose	0.81 2.34	P	P	P	P	a good rubber surface coating. little penetration and excellent coverage.
84	Potters Flint	55	<3	8% phosphoric acid Neoprene 750 (with 270 cp viscosity)	0.66 2.78	P	P	P	P	" " "
85	Beach Sand	97	air dried	8% phosphoric acid Neoprene 400 (raised viscosity to 100 cp with sodium carboxymethyl cellulose.	0.88 2.12	P	P	P	P	" " "
86	Potters Flint	55	<3	8% phosphoric acid Neoprene 400 (with 100 cp viscosity)	1.02 2.70	P	P	P	P	" " "
87	Beach Sand	97	air dried	8% phosphoric acid natural latex (with ~5% polymul C-66)	0.66 1.24	after 2 hours P	-	-	-	coating not tacky.

Test	Soil Type	Dry Soil Density lb/ft^3	Moisture Content, wt. %	Coating	Coating Wet Weight Applied, lb/yd^2	Test Air 1	Test Rain	Test Air 2	Test Air 3	Remarks
88	Beach Sand	97	Air Dried	30% Zinc Chloride 1-V-10 (60% Solids)	0.74 2.36	P	P	P	P	A good rubber surface coating
89	Potters Flint	55	< 3	30% Zinc Chloride 1-V- 0 (60% Solids)	0.51 2.78	P	P	P	P	A good rubber surface coating
90	Beach Sand	97	Air Dried	30% Zinc Chloride Nat. Latex	0.80 2.42	P	P	P	P	A good rubber surface coating but tacky
91	Potters Flint	55	< 3	30% Zinc Chloride Nat. Latex	0.74 2.34	P	P	P	P	A good rubber surface coating but tacky
92	Beach Sand	97	Air Dried	30% Zinc Chloride Neoprene 750	0.95 1.98	P	P	P	P	A good rubber surface coating but tacky and disclored upon setting. Latex penetrated the sand.
93	#55 Sand	90	< 1	8% Phosphoric Acid 1-V-10F (60%)	0.74 2.64	-	-	-	-	A good rubber surface coating but tacky and disclored upon setting. Latex penetrated the sand.
94	#55 Sand	90	< 1	8% Phosphoric Acid 2V42-AG	0.95 2.78	-	-	-	-	A good rubber surface coating but tacky and discolored upon setting. Latex penetrated the sand.
95	#55 Sand	90	< 1	8% Phosphoric Acid 2V50-C	0.88 2.64	-	-	-	-	A good rubber surface coating but tacky and discolored upon setting Latex penetrated the sand.
96	Beach Sand	97	Air Dried	8% Phosphoric Acid 1-V-10F (60%)	0.74 2.34	-	-	-	-	A good rubber surface coating but tacky and discolored upon setting. Latex penetrated the sand.
97	Beach Sand	97	Air Dried	30% Zinc Chloride 1-V-10F (60%)	0.80 2.27	P	P	P	P	A good rubber surface coating.
98	Clayey Silt	55	2	30% Zinc Chloride 1-V-10F (60%)	0.66 2.05	P	P	P	P	A good rubber surface coating.

Test	Soil Type	Dry Soil Density lb/ft^3	Moisture Content, wt. %	Coating	Coating Wet Weight Applied, lb/yd^2	Test Air 1	Test Rain	Test Air 2	Test Air 3	Remarks
99	#55 Sand	90	<1	30% Zinc Chloride 1-V-10F (60%)	1.05 2.12	P	P	P	P	A good rubber surface coating.
100	Clayey Silt	90	13	30% Zinc Chloride 1-V-10F (60%)	0.88 2.50	P	P	P	P	A good rubber surface coating.
101	Beach Sand	97	Air Dried	21% Zinc Acetate 1-V-10F (60%)	0.80 2.05	-	-	-	-	Slight penetration.
102	#55 Sand	90	<1	8% Phosphoric Acid 1-V-10G (60%)	0.80 2.64	-	-	-	-	Latex penetrated the sand.
103	#55 Sand	90	<1	30% Al sulfate 1-V-10 (60%)	1.17 1.91	P	P	P	P	A good rubber surface coating.
104	#55 Sand	90	<1	30% Al sulfate 1-V-10F	0.74 1.91	P	P	P	P	A good rubber surface coating.
105	#55 Sand	90	<1	30% Al sulfate 2V42-AQ	1.10 2.42	-	-	-	-	Latex penetrated the sand.
106	#55 Sand	90	<1	30% Al sulfate 2V73-A	0.80 2.42	P	P	P	f	Large surface cracks formed in the coating.
107	#55 Sand	90	<1	30% Al sulfate 3N10-U	0.74 2.12	P	P	P	P	A good rubber surface coating.
108	#55 Sand	90	<1	30% Al sulfate 2V50-C	0.66 2.42	-	-	-	-	Latex penetrated the sand.
109	#55 Sand	90	<1	30% Al sulfate 1V10G	0.88 2.05	P	P	P	P	A good rubber surface coating.
110	#55 Sand	90	<1	30% Al sulfate Resymul V55P	0.95 2.42	-	-	-	-	Latex penetrated the sand.
111	#55 Sand	90	<1	30% Al sulfate Dow Latex 358	1.10 2.05	P	P	P	P	A strong flexible surface coating.
112	#55 Sand	90	<1	1-V-10	2.56	-	-	-	-	Dried and tensile tested
113	#55 Sand	90	<1	30% Al sulfate Everflex MF	0.95 2.34	-	-	-	-	Latex penetrated the sand.
114	#55 Sand	90	<1	30% Al sulfate Everflex E	0.88 2.12	-	-	-	-	Latex penetrated the sand.

Test	Soil Type	Dry Soil Density lb/ft^3	Moisture Content, wt. %	Coating	Coating Wet Weight Applied, lb/yd^2	Test				Remarks
						Air 1	Rain	Air 2	Air 3	
115	#55 Sand	90	<1	30% Al sulfate Darex - 513 L	0.95 1.98	P	P	P	P	A few small cracks. Low elongation.
116	#55 Sand	90	<1	30% Al sulfate Darex - 517 L	0.66 1.98	P	P	P	P	A good rubber surface coating.
117	#55 Sand	90	<1	30% Al sulfate Heveatex p 1397	0.74 1.48	P	P	P	P	A good rubber surface coating.
118	#55 Sand	90	<1	30% Al sulfate Heaveatex p 1396	0.74 1.54	P	P	P	P	A good rubber surface coating.
119	#55 Sand	90	<1	30% Al sulfate R & H B-89A	0.70 4.03	-	-	-	-	Latex penetrated the sand.

APPENDIX

II POLYMER CLASSIFICATIONS

There are many polymer systems which are suitable for examination in a film-forming approach to dust palliation. Such polymers may be described in discussion of them by different kinds of terminology, according to the context of the discussion. These differences in terminology occasionally seem redundant and unnecessarily complicated; accordingly, the aspects of polymer classification of importance to this application may be defined.

All of the materials of interest, whether termed plastics, resins, or rubbers, natural or synthetic, are polymers, and by polymers are understood substances composed of large molecules having molecular weights in the range of a thousand to a million. The differences in the character of the different polymers derive from the infinite variations of composition, geometry, size, and degree of association of the polymer molecules. This may be represented by the following progression of association symbolizing formation of polymer and their association:

atoms→monomers→chains→associations, ordered or disordered→crosslinked chains

The nature of the atoms composing the basic structural units, or monomers, has much to do with determining characteristics of the final polymer such as reactivity or inertness, affinity for water, etc. Further variety is introduced by the structure of the monomer, in terms of symmetry or branching, and whether one monomer or several are combined in the repeating chemical structural units which make up the long chain super molecule composing the polymer. The relative length of the chains and the variations in the way structural units are distributed along the chain introduce important differences. Of fundamental importance to the usefulness of polymers is the fact that molecules of the large size and extended shape of polymers have large forces of attraction for one another. The strength and orderliness, or lack of it, of these attractions determine the physcial properties of the polymer. The attractive forces are in turn dependent on the structural variations of the molecules as determined by the atoms and monomers of which they are composed. Such association affects melting points, solubility, and the ability of admixed materials to plasticize the polymer. Still stronger association of chains may be obtained by introducing direct primary valence bonds between the chains by chemically reacting, or crosslinking, them. As crosslinking becomes more and more extensive, the solubility and fusibility of the three-dimensional polymer produced decreases.

The foregoing description pictures increasing degrees of association. The reversal of the process, especially the breaking of crosslinks and diminishment of chain length, is degradation of the polymer. In general, once a composition and degree of association has been found useful, any such degradation makes a polymer less well suited for a particular use.

The behavior of a polymer when exposed to thermal or mechanical

stress provides the principal basis used in classification of these materials, the commonest polymer categories being thermoplastic, thermosetting, and rubbery. By thermoplastic are indicated the polymers which are solid at room temperature but become plastic (in the mechanical sense) or convert to viscous liquids at higher temperature. The thermoplastic materials may be softened and returned to their original condition, reversibly over many cycles. The thermosetting polymers are those which, once fused by application with heat, harden or"set", and may no longer be returned to the original condition or fused again. The rubbers are characterized by their ready and substantial elongation, the rapidity and completeness with which such elongation may be recovered, and the relatively high values of tensile strength and elastic modulus exhibited. Some examples of polymers usually identified in these categories are:

Thermoplastics	Thermosetting Plastics	Rubbers
Polyvinyl chloride	Phenolic resins	Natural rubber
Polystyrene	Epoxy resins	Neoprene
Polyethylene	Polyesters (alkyds)	SBR
Polymethyl methacrylate		Butyl rubber
Cellulose esters	Urea & Melamine resins	
Linear silicones		

Although such categories are useful and widely used, they do not provide hard and fast classifications. For example, unvulcanized natural rubber may be considered a thermoplastic; vulcanized (highly crosslinked by reaction with sulfur) or hard rubber is thermosetting plastic. Polyamides and polyesters may be made as thermoplastic or thermosetting plastics. Polyurethanes may be prepared as thermosetting plastics or as rubbers. As polymer technology grows such exceptions and variations become more commonplace.

The physical state of the polymer has much to do with its mode of use. This is of importance in determining the method of application of a polymer for dust control. Thus, according to the nature of the polymer, its method of preparation, and the temperature or pressure to which it is exposed it may be solid, molten, dispersed in a fluid (latex), or dissolved. Dispersions of polymers or solutions of them are especially convenient for distribution in soil treatment, provided that a satisfactory method can be worked out to produce a coherent polymer film from the solution or dispersion. The practice of applying sheet material for dust control constitutes application of polymer as a solid, and in principle molten polymer might be applied from a distributor. The overwhelming ease of application of latex or solution makes these forms by far the more attractive and practical.

Further flexibility and choice of application techniques is offered through working with monomers or partially polymerized monomers, rather than with the completely formed polymer. This procedure is especially useful when working with thermosetting plastics which in the final form are so intractable with respect to fusion or solution that they cannot easily be applied. Thus, the monomers, often fluids, or solutions or dispersions of monomers, may be applied, along with

suitable reactants to cause polymerization. More commonplace is the procedure of reacting the monomers to a limited extent to form relatively large molecules which are soluble or thermoplastic and which will react further to form the complete polymer. An example of such a "prepolymer" is the so-called "B-stage resin" formed by reacting phenol and formaldehyde. This partially reacted material is soluble in water and may be readily pumped or sprayed. On evaporating the water and heating further reaction occurs to produce the final polymer, phenolic resin, which is hard and virtually insoluble. The urea formaldehyde resin investigated in the work reported here is of this category.

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APPENDIX

III IDENTITY OF RAW MATERIALS

Commercial Name	Source	Composition
N-748-N	Pacific Resins & Chemicals, Inc.	Urea-formaldehyde resin (67% solids)
Renex 35	Atlas Chemical Industries	Surface active agent
Everflex GT	Dewey and Almy Chemical Division	Polyvinyl acetate emulsion (54% solids)
Neoprene 750	E. I. DuPont De Nemours & Co.	Polychloroprene emulsion (50% solids)
Geon 576	B. F. Goodrich Chemical Company	Polyvinyl Chloride emulsion
Nitrile Latex 1512	B. F. Goodrich Chemical Company	Butadiene acrylonitrile latex
Pliovic 400	Goodyear Chemical Div.	Synthetic rubber latex
Neoprene 950	E. I. DuPont De Nemours & Co.	Polychloroprene emulsion (50% solids)
Vultex 1-V-10	General Latex & Chemical Corporation	Prevulcanized Rubber latex (60% solids)
Natural Latex	General Latex & Chemical Corporation	Natural rubber latex (57% solids)
Resymul VA 57A-2-1	Resyn Corporation	Polyvinyl acetate emulsion
Dow Latex 358	Dow Chemical Corporation	Polyacrylate emulsion
Geon 980XL	B. F. Goodrich Chemical Company	Polyvinyl Chloride emulsion
Vultex 3-N-100	General Latex & Chemical Corporation	Polychloroprene emulsion
Vultex 2-V-109-A	General Latex & Chemical Corporation	Styrene-butadiene latex

Neoprene 400	E. I. DuPont De Nemours & Co.	Polychloroprene emulsion (50% solids)
Polymul C-66	Nopco Chemical Company	Polyethylene emulsion
Vultex 1-V-10F	General Latex & Chemical Corporation	Prevulcanized rubber latex (60% solids)
Vultex 2V42-AQ	General Latex & Chemical Corporation	Styrene-butadiene latex
Vultex 2V50-C	General Latex & Chemical Corporation	Styrene-butadiene latex
Vultex 1-V-10G	General Latex & Chemical Corporation	Prevulcanized rubber latex (60% solids)
Vultex 2V73-A	General Latex & Chemical Corporation	Styrene-butadiene latex
Resymul V55P	Resyn Corporation	Polyvinyl acetate emulsion
Everflex MF	Dewey and Almy Chemical Division	Polyvinyl acetate emulsion
Everflex E	Dewey and Almy Chemical Division	Polyvinyl acetate emulsion
Darex 513L	Dewey and Almy Chemical Division	Styrene-butadiene latex
Darex 517L	Dewey and Almy Chemical Division	Styrene-butadiene latex
Heveatex P1397	Heveatex Company	Prevulcanized rubber latex
Heveatex P1396	Heveatex Company	Prevulcanized rubber
B-89A	Rohm & Haas Company	Polyacrylate emulsion

APPENDIX

IV TENSILE STRENGTH AND ELONGATION OF COATINGS FORMED ON SOILS

(Test Rate = 5 inches/min)

No.	Coating Composition	Soil	Coating (dried) Weight lbs/yd^2	Elongation at break, %	Tensile at break, lbs/1/2 inch width
88	1-V-10 $ZnCl_2$	Beach Sand (loose)	1.41	725	7
98	1-V-10F $ZnCl_2$	Clayey Silt (loose)	1.23	750	21
99	1-V-10F $ZnCl_2$	#55 Sand (loose)	1.27	700	19.2
100	1-V-10F $ZnCl_2$	Clayey Silt Compacted (13% H_2O)	1.50	612	3.5
103	1-V-10 $Al_2(SO_4)_3$	#55 Sand (loose)	1.14	650	6.4
104	1-V-10 $Al_2(SO_4)_3$	#55 Sand (loose)	1.14	575	2.2
107	3N10-U $Al_2(SO_4)_3$	#55 Sand (loose)	1.27	650	2.2
109	1-V-10G $Al_2(SO_4)_3$	#55 Sand (loose)	1.23	575	6
111	Dow Latex 358 $Al_2(SO_4)_3$	#55 Sand (loose)	1.53	112	2.2
112	1-V-10 (no coag.)	#55 Sand (loose)	1.53	275	2.2

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APPENDIX

V AGING STUDIES OF COATING SOLUTIONS AND EMULSIONS

Composition	Days at 50^{o} C	Spindle* Number	Spindle* Speed RPM	Viscosity at 28^{o} - Centipoises
400 ml N-748-N diluted with 400 ml H_2O	(Start of Test)	LV-1	60	8.1
	1	LV-1	60	7.0
	2	LV-1	60	6.8
	5	LV-1	60	7.5
	8	LV-1	60	8.3
	11	LV-1	60	8.0
	18	LV-1	60	8.1
	25	LV-1	60	8.2
800 ml N-748-N	(Start of Test)	LV-1	12	110
	1	LV-1	12	119
	2	LV-1	12	203.5
	5	LV-1	6	269
	8	LV-1	6	310
	11	LV-1	3	380
	18	LV-2	12	650
	25	LV-2	3	1800
800 ml N-748-N containing 6.4 g Ammonium Carbonate	(Start of Test)	LV-1	12	125
	1	LV-1	12	180
	2	LV-1	12	305
	5	LV-1	6	758
	8	LV-1	6	1240
	11	LV-1	3	2700
	18	-	-	GELLED

* Viscosity measurements were made with the Brookfield Viscometer.

V AGING STUDIES OF COATING SOLUTIONS AND EMULSIONS (continued)

Composition	Days at 50°C	Spindle * Number	Speed RPM	Viscosity at 28° - Centipoises
Everflex-GT	(Start of Test)	LV-2	0.3	50,500
	1	LV-2	0.3	65,600
	2	LV-2	0.3	70,700
	5	LV-2	0.3	71,000
	8	LV-2	0.3	71,000
	13	LV-2	0.3	76,000
	25	LV-2	0.3	99,500
Daratak - B	(0-hrs)	LV-2	0.3	9,500
	1	LV-2	0.3	8,200
	2	LV-2	0.3	9,700
	5	LV-2	0.3	10,900
	8	LV-2	0.3	12,500
	13	LV-2	0.3	11,900
	25	LV-2	0.3	15,000
Neoprene-750	(0-hrs)	LV-1	60	15
	1	LV-1	60	14.3
	2	LV-1	60	15.0
	5	LV-1	60	18.8
	8	LV-1	60	22
	13	LV-1	60	27.5
	25	LV-1	60	45.0
	52	LV-1	30	154.4

* Viscosity measurements were made with the Brookfield Viscometer.

APPENDIX

VI EFFECT OF CONCENTRATION ON THE AGING OF PREVULCANIZED LATEX VULTEX

1-V-10

% Solids	Days at 50° C	Temperature at Viscosity Measurement	Spindle* Number	Spindle* Speed RPM	Viscosity, Centipoises
60%	0	20° C	LV-1	30	142
	7	28° C	LV-1	30	123
	18	28° C	LV-1	30	161
	25	28° C	LV-1	30	141
	43	28° C	LV-1	12	201
40%	0	20° C	LV-1	60	13.5
	7	28° C	LV-1	60	9.2
	18	28° C	LV-1	30	9
	25	28° C	LV-1	30	8
	43	28° C	LV-1	60	9

* Viscosity measurements were made with the Brookfield Viscometer.

APPENDIX

VII EFFECT OF HEAT AGING ON THE TENSILE STRENGTH AND ELONGATION OF COAGULATED FILMS OF LATEX AGED 90 HOURS AT 100° C

(Rate of Elongation: 20 in/min)

Sample	Composition	Tensile, lbs/in^2 Before	After	% Retained	Elongation, % Before	After
Vultex 1-V-10	Prevulcanized Rubber	3105	300	9.6	775	850
Vultex 1-V-10F	Prevulcanized Rubber with Antioxidant	4160	355	8.6	800	700
Vultex 1-V-10G	Prevulcanized Rubber with Antioxidant	2561	767	30.8	788	750
Vultex 3-N-10V	Neoprene with Antioxidant	933	3130	336	1000	950
Heveatex P 1397	Prevulcanized Rubber with Antioxidant	1836	301	16.4	800	850
Heveatex P 1396	Prevulcanized Rubber with Antioxidant	1900	460	24.2	775	750
Geon 576	Plasticized Polyvinyl Chloride	--	--		--	--

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13. ABSTRACT

This report presents the results of a program directed towards the development of materials for use by the military for dust control in the theater of operations. Criteria for defining the desirable properties of such dust control agents have been established, and materials which possess these properties have been procured, formulated, tested, and evaluated. The low material usage rates required (3 lbs per square yard or less) plus the variety of soils and soil conditions over which such dust control agents must be used preclude such treatments from adding to the load bearing capacity of the soil to any appreciable extent. The materials developed, therefore, are designed to be sprayed as liquids on the soil surface and produce coherent, highly flexible and extensible surface layers which effectively seal off the soil surface, preventing generation of dust. The flexible layers formed can withstand considerable deformation without failure. Because of their nature, these dust control agents serve to waterproof the soil as well. Several latex formulations have been developed which passed the laboratory screening tests and which show potential for military dust control purposes. A device has been developed for the simple application of these materials. Urea resin formulations were examined initially and determined to be generally ineffective, due primarily to their inability to withstand deformations of great enough magnitude. Subsequently, emphasis was directed toward synthetic and natural latex systems which show a greater potential.

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